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# THE FORMATION OF COAL BEDS.<sup>1</sup>

## IV.

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(*Read April 18, 1913.*)

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### THE COAL BEDS.

Coal beds are intercalated between rocks of different composition and apparently of different origin. The deposit may cover only a few square yards or thousands of square miles; its changes in thickness may be abrupt or may be so gradual as to be unimportant in a considerable district; the structure may be variable or it may be

<sup>1</sup> Part I. appeared in these PROCEEDINGS, Vol. L., pp. 1-116; Part II., in the same volume, pp. 519-643; Part III., in Vol. LI., pp. 423-553.

so constant as to characterize the bed in great areas; the composition of the several divisions may be similar or in great contrast; the relations of a coal deposit to the associated rocks may be so intimate as to be interdependent or the association have all the appearance of accident. One must study these conditions and their interrelations.

#### EXPLANATION OF TERMS.

Classification of the fossil fuels is foreign to the subject of this work, belonging rather to a study of the origin of coal; here, certain familiar terms are used in a broad sense and the whole series from peat to anthracite is taken to be continuous—at least, from the chemist's point of view. The chemical relations existing between members of the series have been expressed in many ways; but this table from Muck<sup>2</sup> answers the present purpose:

	C	H	O	N
Woody fiber.....	50	6	43	1
Peat.....	59	6	33	2
Brown coal.....	69	5.5	25	0.8
Stone coal .....	82	5	13	0.8
Anthracite.....	95	2.5	2.5	Trace

The mineral content is ignored in this comparison. The table like all others, is merely a generalization and the boundaries between groups are arbitrary. The passage from one to another is gradual and in each the variations are extreme.

Peat is the accumulation of vegetable matter decomposed in presence of a constant supply of water and protected from access of oxygen. It occurs in areas of greater or less extent on the present surface or in Quaternary deposits. Plant structure is readily recognized in the newer portions but, in the thoroughly matured peat, it can be detected only by aid of the microscope. Under prolonged pressure, peat may assume the appearance of typical brown coal. Lesquereux,<sup>3</sup> cited on an earlier page, saw peat exposed midway in the valley of the Locle, where it is dug. At a little way toward the hills, it is covered with 4 feet of marl and is much changed in ap-

<sup>2</sup> F. Muck, "Die Chemie der Steinkohle," 2te Aufl., Leipzig, 1891, p. 2.

<sup>3</sup> L. Lesquereux, "Quelques recherches sur les marais tourbeux," Neuchâtel, 1845, p. 95.

pearance, though still distinctly peat; but on the border of the valley, where the marl is thick, the peat has been compressed to 3 inches and has become a brown coal, hard, fragile and with brilliant fracture. G. M. Dawson<sup>4</sup> found on Belly river, a bed of interglacial peat, hardened by pressure so as to have the appearance of lignite.

Brown coal or lignite exhibits a more advanced stage of chemical change and is the ordinary type in Mesozoic and Tertiary deposits, though it is not wanting in the Quaternary, for the beds at Dürnten and elsewhere in Switzerland as well as at localities in Bavaria must be accepted in great part as brown coal. At times, vegetable structure is thoroughly well preserved, especially where stems of trees are present; at other times, the whole mass is amorphous, while at still others, both forms occur in a single layer, recalling the condition so often seen in mature peat. Lamination is reported from many localities. The color varies from dingy brown to coal black and the luster from earthy to brilliant, but the streak is brown. Brown coal is not unknown in Palæozoic deposits. The great beds of the Decazeville basin, France, two of which have a maximum thickness of more than 100 feet, show all external characteristics of stone coal, but they contain more oxygen and nitrogen than is found in ordinary brown coal and more than twice as much as is present in air-dried stone coal.<sup>5</sup> The brown coal from Tula in Russia has been studied by many palæobotanists. In spite of its ancient origin, it approaches very closely to lignites in appearance and composition. Nikitin<sup>6</sup> states that there are several beds, more or less important, in the lowest part of the Carboniferous and that boghead is associated with the coal. In this connection, it may be well to recall the remarkable observation by David,<sup>7</sup> which appears to have been overlooked. He discovered in soft fine clay of Carboniferous age thickly matted

<sup>4</sup> Cited by J. W. Dawson, "Canadian Ice Age," 1892, p. 724.

<sup>5</sup> N. Saint-Julien, cited by J. J. Stevenson, "The Coal Basin of Decazeville, France," *Ann. N. Y. Acad. Sci.*, Vol. XX., 1910, p. 272.

<sup>6</sup> S. Nikitin, "De Moskou à Koursk," *Guide des excurs. VII., Cong. Géol. Int.*, 1897, XIV., p. 5.

<sup>7</sup> T. W. E. David, *Ann. Rep. Dept. of Mines, New South Wales*, 1890, p. 229.

layers of undecomposed *Glossopteris* leaves, not brittle but retaining their original substance; soaked in glycerine and water, they can be unrolled and laid flat. A large number of the specimens were mounted and placed on view in the museum of the Department of Mines at Sydney.

Stone coal marks a still greater advance in chemical change. With rare exceptions, it is laminated, black or grayish black, more or less lustrous and with a black streak. In nearly all stone coals, there are alternations of bright and dull laminæ, the Glanz- and the Mattkohle of von Gümbel, which may be extremely thin or several inches thick. Usually, there is little macroscopic evidence of plant structure, aside from the mineral charcoal, mother of coal, fusain, Faserkohle of authors, which resembles charred tissue. This is the ordinary coal of the Carboniferous and it is present in many localities of later Cretaceous age. The difficulty encountered in the effort to define a limit between brown and stone coal is increasingly great, as the determination is of commercial importance in the western United States, especially in areas where both types occur in the Mesozoic. Stone coals have been divided commercially into bituminous and semi-bituminous on the basis of volatile content, but this does not suffice for distinction from the brown coals. The latter have been termed hydrous coals because they contain much water, apparently combined, and break up rapidly on exposure to the air. But many so-called anhydrous coals break up with equal readiness on exposure to dry air. It is quite certain that typical Carboniferous coals have, for the most part, a definite prismatic cleavage and that many brown coals lack that feature, while some have it. Many methods of distinguishing the types have been suggested, but none is satisfactory; the exceptions are too numerous to prove the rule. No hard and fast line between brown and stone coals exists except in generalized tables; but, as a rule, the older coals are more advanced in chemical change than those in later deposits.

Anthracite resembles stone coal in structure and often in appearance, but it is more brittle and more brilliant. The volatile content is small, often approaching a trace. Like the stone coal, it often contains much mineral charcoal, thus showing relationship to the

other members of the series, since mineral charcoal is a common constituent of the brown coals as well as of peat.

The series is continuous. By slow destructive distillation under pressure all can be converted into anthracite. The coal at Decazeville is much given to spontaneous combustion and the operators suffer great loss not only by destruction of the coal but also by conversion of much into a dense brilliant anthracite. The change of brown coal into anthracite by eruptive rocks is a common phenomenon in both Europe and America, so common that anthracite is thought by the great majority of students to be a metamorphic coal.

Beside the ordinary coals, which have so many features in common, there are some which might be termed aberrant forms, the cannels, bogheads, kerosene shale; these, which have been termed sapropelic coals, are minutely laminated, brownish black and have a brownish streak. Ordinarily, they are rich in volatile constituents, which give much more brilliant flame than those from bituminous coal. In mode of occurrence and in some structural features they resemble the organic muds or sapropelites of Potonié, which are found in many ponds and in lakelets within peat swamps. They, like the other coals, are composed of changed plant material, but they frequently contain animal remains.

All coals have more or less inorganic material, the ash or incombustible portion. At times the quantity is insignificant, less than 1 per cent. but it often exceeds that of the combustible matter, in which case the rock is known not as coal but as carbonaceous or bituminous shale.

#### THE EXTENT OF COAL DEPOSITS.

The areas of individual coal deposits vary from a few square yards to many hundreds of square miles. Those of very limited extent are, usually, outlying patches, occupying spaces eroded in older rocks and they abound in some of the western states, where the coal rests unconformably on beds of Mississippian or even greater age. Hall<sup>\*</sup> described several in Iowa, most of which consist of

<sup>\*</sup> James Hall, Rep. Geol. Surv. Iowa, 1858, Vol. I., pp. 121, 124, 126, 130, 131, 133; A. H. Worthen, *ibid.*, pp. 212, 223, 234.

impure cannel. Worthen found many. They are from 150 feet to 2 or 3 miles in diameter, contain well-defined underclays with more or less coal. In one, the coal dips to the center of the little basin; in another, the coal thickens toward the center; in others, the coal is irregular, but in all the coal thins out in approaching the border. At one locality, marine limestone rests directly on the coal. Bain<sup>9</sup> has discussed these localized deposits and has explained the concave upper surface of the coal as due to consolidation of the vegetable material.

Similar small basins are numerous in Missouri, directly south from Iowa, and occasionally they are of commercial importance. Swallow<sup>10</sup> says that some contain cannel, others, ordinary coal; but the noteworthy feature is that in all the deposit is thick. In one he saw 20 feet of good coal underlying 6 feet of cannel. Meek examined several in undisturbed Mississippian beds and others which occupied hollows in Silurian limestones. Impure cannel is the prevailing material but he saw good coal in one basin. Later observers have gone more into detail. Potter<sup>11</sup> described a basin, only 200 yards in diameter, which yielded 22,000 tons of coal; it had two coal beds, 2 and 16 feet thick. Another, 115 yards in diameter, yielded 3,730 tons; its coal bed, with maximum thickness of 8 feet, thinned away on the borders. One, examined by Winslow, occupies a hollow in the Magnesian (Lower Ordovician) and holds a coal bed, almost 7 feet thick midway, and roofed with 7 inches of clay, on which rests fossiliferous calcareous shale. More remarkable pockets were described by Ball and Smith and were thought by them to occupy "sink holes." In one case, the diameter is somewhat more than 270 feet, while the depth is more than 130. Shale, 38 feet

<sup>9</sup> H. F. Bain, Iowa Geol. Surv., Vol. VII., 1897, p. 300.

<sup>10</sup> G. C. Swallow, First and Second Ann. Reps. Geol. Surv. Missouri, 1855, Part I., pp. 191-193; F. B. Meek, *ibid.*, Part II., pp. 112-114; Reps. Geol. Surv. Mo., 1855-1871, 1873, pp. 132, 149.

<sup>11</sup> W. B. Potter, "Preliminary Report on Iron Ore and Coal Fields," Geol. Surv. Mo., 1873, pp. 271-274; A. Winslow, "Preliminary Report on the Coal Deposits of Missouri," 1891, pp. 168-171; S. W. Ball and A. F. Smith, "Geology of Miller County," Bureau of Mines, Vol. I., 1903, pp. 100, 105, 107, 108, 111.

thick, is at the bottom and on it rests bituminous coal, 32 feet. The coal in all the pockets is rather impure. Meek thought that the coal beds had been let down by solution of the underlying limestone, but studies by later observers make evident that the accumulations were deposited in preëxisting hollows.

Ashley<sup>12</sup> described a small area occupying a basin of different type, eroded in the Merom sandstone of Sullivan county, Indiana. This is in the upper part of the Coal Measures and is regarded by him as evidence of a land surface. The coal is thickest in the middle of this basin and thins away in all directions toward the border. The lower coal beds in Indiana exhibit a tendency to this basin shape, the thinning of coal toward borders of the "swamps" being a common feature. But higher in the column, the areas increase and at length the coal beds are practically continuous for long distances.

The condition, noted by Ashley in Indiana, prevails in the northern part of the Appalachian basin, where extreme irregularity decreases after the close of the Pottsville, and the coal becomes reasonably continuous in greater areas, so that mining enterprises are attended by less risk. But the irregularity was very great in the Pottsville. Reference has been made in another connection to Roy's description of the mode in which the Sharon coal bed occurs, which confirmed the statements made by Newberry, Read and others in the Ohio reports. The same features characterize the Beaver beds in Pennsylvania, of which Ashburner<sup>13</sup> says that in the northern counties of the state they occur in "swamps," "swallows" or "sumps," and that they are saucer-shaped; the coal thins to a knife-edge on the hillocks of sand but is reached again when those have been pierced. I. C. White<sup>14</sup> was able to study the vagaries of the Sharon coal bed in a mine with 10 miles of workings. The coal rests on 1 to 2 feet of fireclay, overlying the Sharon sandstone.

<sup>12</sup> G. H. Ashley, "The Coal Deposits of Indiana," 23d Ann. Rep. Geol. Surv. Ind., 1899, pp. 22-24, 532, 633, 666, 909.

<sup>13</sup> C. A. Ashburner, Sec. Geol. Surv. Penn., Rep. R, p. 53; Rep. RR, pp. 95, 97.

<sup>14</sup> I. C. White, Sec. Geol. Surv. Penn., Rep. Q, pp. 194, 202; Rep. QQ, p. 170; Rep. QQQ, p. 123.

The floor is uneven, characterized by "hills" and "swamps," the coal being 4 to 5 feet thick in the latter but thinning away to almost nothing on the former, which are merely piles of pebble rock, rising at times with a slope of 15 degrees. The "swamps" are depressions among the "hills," which White thinks are due to erosion, as the pebble rock varies from 6 to 25 feet, the least thickness being under the swamps. This condition occurs less commonly in higher beds, but it is by no means rare. The Lower Kittanning, in Lawrence county, rests on an uneven floor of fireclay which has an extreme thickness of 10 feet. The coal often dips into swamps with increased thickness at the rate of one foot to the yard; it decreases usually about one half on the hills. The reports by Chance and W. G. Platt note similar conditions in other coal beds of the Allegheny; these are only too familiar in the Conemaugh.

#### ARE COAL BEDS CONTINUOUS?

The query at once presents itself, are these petty areas exceptional or are they typical? They are from a few yards to several miles in diameter, and one might expect to find yet larger areas, distinctly limited. The question is of great economic importance and the answer is of equal importance in relation to the problem in hand. Are coal beds continuous or do the names applied to them designate only horizons, marking periods when accumulation of coal took place, so to say, contemporaneously at many places and in extensive areas?

The question has been raised less frequently in Europe than in the United States because the coalfields are of comparatively small extent. But in the bituminous region of the Appalachian generalizations presented long ago still hold in the nomenclature, though some observers have opposed them strenuously. The early surveys were made when the region was thinly settled, when mining operations were unimportant and exposures of coal beds were mostly in small pits opened for local supply. There were few records of shafts, there were no records of borings and there were few graded roads; the section was worked out laboriously from natural exposures and without aid of the instruments now regarded as an

essential part of the geologist's equipment. The writer had as his duty, almost 40 years ago, the work of studying in greater detail extensive areas examined 30 years before by pioneer laborers in the northern part of the Appalachian basin. He has never been able to restrain the feeling that the work of those early geologists bordered on the miraculous—the intuition of Hodge, Jackson, Henderson and J. P. Lesley seems to him almost more than human. Even at the time of revision by geologists of the Second Geological Survey of Pennsylvania, the conditions, though better, were poor enough; dependence had still to be placed mostly upon natural sections, for the great mining industry was still in infancy and deep borings for oil were unknown. The defective conceptions inherited from the preceding generation were accepted and continuity of coal beds was taken as the fact, barren areas being regarded as exceptional. This belief was strengthened by the known distribution of the Pittsburgh coal bed, which appeared to have been proved within an area of not far from 15,000 square miles. But the multitude of shafts, the vast number of oil-well records, the increased number of natural exposures due to railway and road construction have provided data during the last twenty-five years, which compel modification of opinion.

When I. C. White, after study of oil-well records in West Virginia, announced that the Pittsburgh coal is wholly absent from fully one half of the area enclosed within the outcrop, the announcement was received with surprise. Stevenson, nearly twenty years earlier, had reached the conclusion that the Allegheny coal beds, for the most part, were wanting in the interior portion of the bituminous region, but White's study of the well records gave the evidence. There is a continuous area of about 10,000 square miles in which coal accumulation was very irregular from the end of the Pottsville to the close of the Carboniferous. But the irregularity is not confined to the central area; it is characteristic, to a less extent, of the whole region.

The conception of continuity was a normal conclusion from the available facts. A coal bed was generally found almost directly under the Mahoning sandstone, resting on a fireclay which overlay

a limestone. Many times an exposure was incomplete, some portion of the little group was concealed but enough was seen to make recognition definitive. The coal was observed so often that, when its place was concealed, its presence was assumed. The bed was mined at that time near Freeport in Pennsylvania and the deposit was named Upper Freeport. Either coal or very black shale was exposed so often in this position both in Pennsylvania and Ohio that barren spaces were regarded as due merely to petty local conditions and the supposedly continuous deposit was called the Upper Freeport coal bed. In like manner, the other horizons became known as coal beds and widespread accumulation of coal at each horizon an accepted fact, without reference to either quantity or quality of the material.

But detailed study of individual coal beds proves that in all there was great irregularity. The Pittsburgh, Waynesburg and Washington, in the upper portion of the series, approach as nearly to continuity as one may conceive, for they are always present in exposures and records within an area of thousands of square miles; but the Pittsburgh shows remarkable variations in thickness; it thins away to nothing from all sides toward the central part of the area while at times only its underclay remains to mark the horizon. The Waynesburg and the Washington horizons are persistent, coal or black shale being present, but there is often only a trace of coal, while the variations in structure of the deposit are extreme. Some Conemaugh coals are practically continuous, according to natural exposures, in Ohio within an area of not far from 1,000 square miles, but they are rarely seen in Pennsylvania; others are present on the east side of the region and rarely appear on the west side. The Allegheny conditions are similar; one bed attains great commercial importance within an area of perhaps a thousand square miles in Ohio, but in Pennsylvania and West Virginia, it is only occasionally important and it is practically wanting in considerable areas. And the statement is true of other coal horizons. The evidence goes to show that there were periods, longer or shorter, during which proper conditions existed, so to say, contemporaneously in many localities but did not exist in very many others. The

greatest unbroken area, after the close of the Pottsville, in which coal accumulated, was that at the Pittsburgh horizon, the coal having been proved up in an area of approximately 8,000 square miles. Originally it was greater, for erosion has removed much. The Sewanee coal bed of the New River seems to have a great continuous area, but the measured sections are somewhat widely separated; they suffice to prove identity of horizon, but they do not justify either assertion or denial of continuity.

Accepting, however, the extreme conceived area for original extent of the Sewanee or the Pittsburgh, one is compelled to recognize that accumulation of coal was not in process at any time in an area of more than 30,000 square miles and that it never was in process simultaneously in all parts of that area; that at most horizons, conditions were favorable to accumulation in areas of a few square miles to some hundreds of square miles while in perhaps the greater part of the regions the conditions were unfavorable. In fine, that the conditions were very much like those existing to-day. And this has always been the case. The Triassic coals were formed in narrow areas; the inconstancy of Upper Cretaceous coals in New Mexico, Colorado and Utah is proverbial—they are spoken of as lenticular; Tertiary brown coals exhibit the same features, which are equally characteristic of Quaternary deposits as well as of peat accumulations of this period. At all periods, conditions favorable to accumulation of coal have existed in comparatively small areas, more or less widely separated. This will be considered in another connection.

The relation of coal to the immediately adjacent rocks is so intimate that they must be regarded as one: a coal bed consists of the floor, *mur*, *Liegende*; the coal, *houille*, *Kohle*; the roof, *toit*, *Hangende*, each of which must be examined in detail.

#### THE FLOOR OF THE COAL BED.

Miners, long ago, recognized that coal beds ordinarily have a clay floor or seat, but the fact was announced as generalization first

by Mammatt<sup>15</sup> after his study of the Ashby-de-la-Zouche basin. Logan<sup>16</sup> reached the same conclusion independently, several years afterward, as the result of studies in south Wales. His statements led to a comparison of notes and the conditions seemed to be the same everywhere. The relations of the Illinois coal beds have been cited as evidence that the condition is by no means general, but the citation is an error, for Worthen's<sup>17</sup> remarks are so clear that one is at a loss to comprehend how the error came about. He says

The typical fireclay, the "underclay," "seat," or "mur" is rather fine in grain, somewhat sandy, very light gray to almost black, the tint depending on presence or absence of vegetable matter. Carbonate of iron is almost invariably present, sometimes in very small quantity but many times it is abundant in nodules. Alkalies are comparatively unimportant, though often present in sufficient quantity to unfit the material for firebrick. Ordinarily, the rock is plastic, but occasionally it is hard and non-plastic, a "flint clay." This clay seldom shows lamination and on exposure to the air it breaks up quickly into irregular angular fragments. The remarkable feature is the presence of *Stigmara*, whose rhizomas are often interlaced in very complex manner. Owing to the abundance of the plants, the clay is often termed *Stigmara*-clay; but the presence of that plant is not essential; where *Sigillaria* and *Lepidodendron* are wanting or of rare occurrence, *Stigmara* is absent. It has not been reported from underclays of the Monongahela or higher formations in the Appalachian basin.

The "coal-seat" is not always clay or even impure sandy clay.

<sup>15</sup> E. Mammatt, "Coal Field of Ashby-de-la-Zouche," 1834, p. 73.

<sup>16</sup> W. E. Logan, "On the Character of the Beds of Clay, Lying Immediately Below the Coal Seams of South Wales," *Proc. Geol. Soc. Lond.*, Vol. III., pp. 275, 276.

<sup>17</sup> A. H. Worthen, *Geol. Surv. Illinois*, Vol. I., 1866, p. 59.

"The coal seams are usually underlaid by a bed of fireclay, which varies in thickness from a few inches to ten or twelve feet. This was the original soil on which the vegetation that formed the coal grew, and it is often penetrated by the rootlets of the ancient Carboniferous trees, whose trunks and branches have contributed to form the coal."

Hantken<sup>18</sup> gives a section at a Hungarian locality showing 8 coal beds from 0.15 to 3.10 meters thick, of which four have clay and four have sandstone as the floor. Coal deposits were formed on clay, shale, sandstone or even limestone, the conditions being apparently the same as those observed in the study of peat accumulations. The Triassic coal of the Richmond area in Virginia was long supposed to rest on granite. Taylor<sup>19</sup> mentioned the recognized fact that the coals of that area rest directly on granite, though occasionally a foot or two of shale may intervene. Bosses of granite rise as eminences and interfere with mining. This opinion was shared by W. B. Rogers in 1843 and at a later date by Lyell, who asserted that the lower coal bed is in contact with the fundamental granite. The true condition was ascertained by Shaler and Woodworth,<sup>20</sup> who showed that the granite contact is due to faulting and that, normally, there is a notable interval, sometimes 300 feet, filled with barren rocks. There is no *a priori* reason, however, why coal might not accumulate on a granite seat. Chevalier's description of the peat growth on granite and gneiss in the Niger region makes this clear enough.

Cores from diamond drilled holes in the anthracite areas of Pennsylvania indicate in many cases that coal beds of notable importance rest directly on conglomerates or are separated from them by a mere film of clay. The cores show all gradations in the floor from fine clay to conglomerate. Similar conditions exist elsewhere. The hard silicious rock, known as "Ganister,"<sup>21</sup> is at times in contact with the overlying coal bed in the Yorkshire field. Sections in other British fields show that a sandy floor is a by no means uncommon feature, though clay is the usual material.

Limestone of marine or freshwater origin is frequently the floor

<sup>18</sup> M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in den Ländern der ungarischen Krone," Budapest, 1878, p. 131.

<sup>19</sup> R. C. Taylor, "Memoir of a Section Passing through the Bituminous Coal Field near Richmond in Virginia," *Trans. Geol. Soc. Penn.*, Vol. I., Part II., 1836, pp. 286, 287.

<sup>20</sup> N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," 19th Ann. Rep. U. S. Geol. Surv., 1899, Pt. II., pp. 424-426, 429, 430.

<sup>21</sup> A. H. Green, "The Geology of the Yorkshire Coal Field," 1878, pp. 19, 26.

of a coal bed. Several coal beds in the Monongahela and higher formations within the Appalachian basin rest at times on fresh-water limestone or calcareous shale; at others clay or shale inter-venes, so that in different parts of the area the same coal rests on clay, shale, sandstone or limestone. Two coals of the Conemaugh in Ohio show similar relations to a marine limestone, sometimes in contact with it, at others, separated by several feet of shale or other material.<sup>22</sup> C. Robb in 1876 reported 6 inches of limestone directly under a Canadian coal bed, and J. W. Dawson in 1868 described a coal bed which overlies a bituminous limestone, containing *Naia-dites* and *Stigmara*, the latter, in his opinion, being evidently in place. Not many instances of coal resting directly on marine limestone are recorded from the Appalachian basin, because, with one exception, the marine limestones are, geographically considered, very unimportant members of the column. Nor is the occurrence frequent in any field, so far as the writer can discover, though there are many localities where the interval is not more than a foot. Worthen states that the Coal 1 of Illinois usually overlies 2 to 3 feet of fireclay, but the fireclay is often absent and the coal rests directly on the St. Louis limestone. This, however, is not of the type under consideration, for the case is one of pre-Pennsylvanian erosion; the Illinois Coal 5 occasionally rests on a nodular limestone and Coal 6 is frequently in contact with the underlying marine limestone. Ricketts has described a number of coal pockets in Lower Carboniferous limestone of England but they do not concern the matter in hand, for they are clearly like the Iowa and Missouri pockets, in cavities eroded when the limestone was above water.

Crampton,<sup>23</sup> however, has given notes which do concern the matter. Presenting the results of studies in East Lothian, Scotland, he refers to the lowest limestone as essentially a coral reef with an abundant marine fauna. Portions of the surface were converted

<sup>22</sup> J. J. Stevenson, Sec. Geol. Surv. Penn., Rep. K, 1876, pp. 94, 96, 116, 270, 349; Rep. KK, 1877, pp. 52, 163, 179; "Geology of Ohio," Vol. III., 1879, pp. 183, 211, 224, 240, 256.

<sup>23</sup> C. B. Crampton, "The Limestones of Aberlady, Dunbar and St. Monans," *Trans. Edinb. Geol. Soc.*, Vol. III., 1905, pp. 374-378; "Fossils and Conditions of Deposits, a Theory of Coal Formation," *ibid.*, Vol. IX., p. 74.

into white marl, consisting of pulverized coral. In most places, where the horizon is exposed, a coal bed is seen overlying this reef and often in direct contact with the limestone. Great branching *Stigmariæ* grew upon the rock, following all irregularities of the surface as they pushed their way through the marl. Limestone under brown coal is reported from the Tertiary<sup>24</sup> as well as from the Quaternary and it occurs frequently under peat deposits of the Recent period. Evidently, *Stigmaria* cared less for the soil than for other conditions, just as do many plants of this day. The relations of coal to the seat are very like those observed in peat deposits, where the accumulation may begin on clay, sandstone, limestone or even on bare consolidated rock, if only the essential condition of moisture be present. Temperature is not all-important, for peat accumulates as well in the tropics as in the temperates, wherever peat-making conditions exist. It fails in the tropics precisely as it does in the temperates, when the peat-making conditions are absent. The relations were the same in earlier periods, for Wall and Sawkins<sup>25</sup> report their discovery of 37 coal beds in the Miocene of Trinidad, of which 5 are workable, with a thickness of 19 feet; and this coal-bearing formation was followed by them on the mainland in an area of 36,000 square miles. And the condition still exists on that mainland. Harrison<sup>26</sup> says that tropical peat, known as "pegass," occurs behind the fringes of courida and mangrove in many parts of the low-lying coast lands of British Guiana and that it is from 1 to 10 feet thick, though usually 2 to 4 feet. He pointed out that, on the pegass land, the alternation of wet and dry seasons allowed both marsh and ordinary plants to grow and that considerable areas were covered with forest of the Aeta palm.

*Stigmaria* is present in a great proportion of the underclays. The manner of its occurrence has been described on earlier pages and only passing reference is needed here. Sorby, Platt and Daw-

<sup>24</sup> C. v. Gümbel, "Beiträge," etc., pp. 149-151; O. Heer, cited in "Formation of Coal Beds," these PROCEEDINGS, Vol. L., p. 623.

<sup>25</sup> G. P. Wall and J. G. Sawkins, "Report on Geology of Trinidad," London, 1860, pp. 112, 197.

<sup>26</sup> J. B. Harrison, "Pegass of British Guiana," *Quart. Journ. Geol. Soc.*, Vol. LXIII., p. 292.

kins have testified that, in the cases described by them, the arrangement of the rhizomas proved not only that the plants are *in situ* but also that the direction of prevailing winds was the same during the Carboniferous as now. The immense extent of roots, spread out in normal attitude, as in the plants described by Adamson, Williamson, Potonie and others, compels those students to assert that no conceivable mode of transportation can explain the phenomenon. The interlacing of the roots, shown by Schmitz, Crampton and many others, is regarded as affording strong confirmatory evidence of *in situ* growth. Many coal beds are divided by clay partings of variable thickness; *Stigmaria*, at times, occurs abundantly in such partings. Robb's remarkable specimen was rooted in such a lens of fireclay. But *Sigillaria* and *Lepidodendron*, to which *Stigmaria* belongs, are not the only coal-making plants; just as peat is composed of many plants or of different assemblages of plants in various parts of the world, so coal in one area was formed of plants unlike those in another. There are great coal deposits containing no *Sigillaria* or *Lepidodendron* and consequently the underclay is without *Stigmaria*.

Occasionally rootlets are found so arranged as to make certain that the materials had suffered no disturbance. Ward,<sup>27</sup> visiting the Saint-Etienne coal field after the Geological Congress of 1900, saw many instances in which the finest fibrils of roots of erect *Calamites* passed across the planes of bedding down the conglomerate, which formed the original floor; the condition was regarded by him as incompatible with the slightest movement. Bertrand<sup>28</sup> observed rootlets *in situ* in an underclay within the Grande Couche at Decazeville; and the writer saw threads of coal descending into an underclay in the upper part of the Campagnac coal bed of the same basin, which suggested rootlets. Fox-Strangways<sup>29</sup> states that he saw rootlets passing downward from the Four-

<sup>27</sup> L. F. Ward, "The Autochthonous or Allochthonous Origin of the Coal and Coal Plants of Central France," *Science*, N. S., Vol. XII, 1900, p. 1005.

<sup>28</sup> P. Bertrand, in letter of January 15, 1911.

<sup>29</sup> C. Fox-Strangways, "Geology of South Leicestershire and South Derbyshire Coal Field." *Mem. Geol. Surv.*, 1907, p. 52.

foot coal into the underclay. D. White, in a letter, says that, during his studies in Kansas and Missouri during 1912, he failed at only one mine to find satisfactory evidence of roots *in situ* in the underclay. At one locality in Kansas, the sandy fireclay contains beautifully preserved interlaced vertical roots while at others in both states absolutely good roots are present.

Bennie and Kidston<sup>30</sup> found spores abundant in underclays, especially within the first 2 or 3 inches below the coal; they cite two localities in which the lower part of the thin clay is barren while the upper portion contains the forms abundantly.

Underclay without coal is by no means rare. Sometimes it underlies black shale with plants *in situ*; in some cases it alone marks the horizon which elsewhere shows a coal bed. In other cases, it is a "forest bed," marking a locality where conditions did not favor accumulation of plant material or where the coal was removed by erosion. Dawson has described many of these and Grand'Eury says that the phenomenon of vegetable soils is as familiar in the Loire basin as it is in Canada. Strahan<sup>31</sup> has given a recent illustration. In the new South Dock excavation at Cardiff, 11 feet of gravel underlies 19 feet of brown and blue clay with some sand. In this gravel were found several upright stumps, about 2 feet high, "rooted in a black clay with stems, the roots extending down into the red marl."

Boulders have been found in the underclay. Ashley<sup>32</sup> states that the underclay of Coal IV. is soft and fine but, in places, full of boulders. This is the only American record, aside from an incidental note by Gresley, that the writer has discovered, but he has been assured that waterworn fragments do occur in the underclay. Apparently they are not numerous enough at most places to attract attention and the occurrence may be regarded as infrequent. Most probably, the pebbles were laid down on the river plain prior to

<sup>30</sup> J. Bennie and R. Kidston, "On the Occurrence of Spores in the Carboniferous Formation of Scotland," *Proc. Roy. Phys. Soc. Edinb.*, Vol. IX., 1888, pp. 102, 103.

<sup>31</sup> A. Strahan, "Geology of South Wales Coal-Field," III., 1902, p. 94.

<sup>32</sup> G. H. Ashley, "The Coal Deposits of Indiana," 23d Ann. Rep. Geol. Surv. Ind., 1899, p. 543.

deposition of the clay, which filled the interstices, so that they may be sought in thin deposits or at the bottom of those which are thicker.

Underclays are often very light in color and many of them contain little iron and less carbon; but some iron is always present even in the most refractory. There is similar variation in the content of alkalies. The absence of iron is believed to be due in chief part to decaying vegetation. The deep red shales of the Coal Measures contain little organic matter, few traces of plants or animals. That organic acids, formed during decomposition of vegetable materials, give somewhat soluble salts with iron has been known for a long time, as was shown on earlier pages where are recorded the results obtained by A. A. Julien and others. Miller,<sup>33</sup> in describing the Boulder Clay of Cromarty, Scotland, gave a local illustration. On the flat moor upland, where the water stagnates over a thin layer of peaty soil, chance sections exhibit the underlying clay spotted and streaked with grayish-white patches. There is no difference between these patches and the red mass in which they occur, all alike consisting of mingled arenaceous and aluminous particles. The stagnant water above, acidulated by its vegetable solutions, seems to be connected with these appearances. In every case, where a crack gives access to the oozing moisture, the clay is bleached for several feet downward to nearly the color of pipe clay. The surface, too, wherever divested of the vegetable soil, presents for yards together the appearance of sheets of half bleached linen. Dawson<sup>34</sup> observes that underclays have the white aspect which one sees in the subsoil of modern swamps, and he thinks that the cause is the same in both cases—the removal or transportation of ferruginous coloring matters by the deoxidizing or dissolving action of organic acids or of organic materials in decomposition.

Stainier<sup>35</sup> has taken exception to this statement of the conditions and has shown that of 150 specimens of Belgian underclays, barely a

<sup>33</sup> H. Miller, "The Cruise of the *Betsy*," Boston, 1862, p. 357.

<sup>34</sup> J. W. Dawson, *Quart. Journ. Geol. Soc.*, Vol. X., 1854, p. 14.

<sup>35</sup> X. Stainier, "Notes sur la formation des couches de charbon," *Bull. Soc. Belge Géol.*, Vol. XXV., 1911, P. V., pp. 73-91.

dozen failed to become distinctly red on burning. Those which failed were mostly sandy and two of them were typical "fire-clays." He has found that carbonate of iron frequently occurs as kidneys in the mur—indeed he regards the presence of such kidneys as in some way characteristic of the mur. The immediate provocation for Stainier's discussion was the statement by Mourlon<sup>38</sup> that "the mur represents the soil on which grew the now buried and metamorphosed forests of the coal epoch. The forests then as now had the property of taking away the iron disseminated in the soil." It is certain that Mourlon and Dawson, in their generalized statement, have written with too little reserve, for neither one of them could have intended to assert that vegetation had removed all iron from the clay. One reading Dawson's publications sees at once that he was familiar with the occurrence of clay ironstone kidneys in underclays. Stainier says correctly that, if coal be of *in situ* origin, the iron should be returned to the soil when the trees die; but it is evident that he reasons from conditions existing in an upland forest, which are as a rule very different from those upon which the *in situ* doctrine insists. Vegetation undergoing chemical change in swamps does not disappear but becomes peat; only a very small part of the inorganic matter could find its way back to the mur; it would remain in the peat. The mur is merely the soil in which the vegetation began; before long, the decomposing plant material becomes the soil and all relation to the mur ceases. The conception that trees cannot thrive in or on peat is a curious survival, which retains its place in argument although it is contrary to fact. As has been shown in an earlier part of this work, the plant life of swamps is not confined to mosses and humble plants but it includes large shrubs and great trees. Among the latter are some of the noblest forms on the American continent, which certainly thrive as well in swamps as on drier land. Very many plants cannot live on the acid soil of peat, but there are very many others which cannot thrive on soil of any other type. As will appear on a later page, accumulation of peaty matter makes possible only indirect action on the mur or original soil, and that is due only to the

<sup>38</sup> M. Mourlon, "Géologie de la Belgique," Bruxelles, 1880, Vol. I., p. 121.

sinking of dissolved humic and other organic acids, which reaching the bottom may remove iron and alkalies from the clay as they do from the peat. If the original quantity of iron in the mur was small, all or practically all might be removed; but if large, the greater part would remain. In any event there would be a chemical change and the color would become lighter, though enough iron might remain to become distinct after burning.

The tinting of underclays depends in great measure on the quantity of carbon present. Changes during conversion would remove some vegetable matter, but not much, for drainage would be chiefly along the surfaces of roots, which may account for the lack of a coal crust, so often observed in *Stigmaria*. The removal could not be extensive throughout the mass, so that if the original quantity was considerable, the clay would be blackened.

The suggestion has been made that gray or whitish murs are not common and that the tint is not original, for, at some distance from the outcrop, the color is not distinctive. The light-colored English clays, it is stated, have been exploited only along the outcrop, where the passage of pluvial waters would be able in time to remove the coloring substances. How effective this pluvial leaching would be in material so nearly impervious as consolidated underclays, the writer cannot determine. On old outcrops of clays and clay shale at roadsides, he has found little evidence of removal of iron and carbon. There is usually a fixation of the iron while the bleaching, as a rule, is insignificant—usually apparent rather than real and due to disintegration or powdering. It may be that the English clays have been exploited only along the outcrop but the case is different in the Appalachian basin. The tints are not confined to the outcrop. Clays have been mined at several localities in Pennsylvania and Maryland during 30 to 60 years, while in Ohio and West Virginia similar work has been continuous for 60 to 80 years. Very many of the mines work up the dip and are "bone dry" with thick cover, at times hundreds of feet, through which no water passes. Pluvial leaching has not existed there. The clay in these mines at a few feet from the outcrop is like that obtained at 1,000 or 2,000 feet farther inside, with pockets of varying tint and of varying composition—the latter

often so serious that great care must be taken in selection for the manufacture of high grade fire-brick. A similar condition was observed in mines working down the dip, the only difference being that the effects of freezing and thawing were perceptible to a somewhat greater distance. H. Ries has informed the writer that the effect of weathering rarely extends beyond 15 feet in a horizontal bed of clay.

The source of the clays is not always clear. It is true that clay is not always present under coal beds, for those rest indifferently on clay, limestone, shale sandstone or conglomerate, just as modern peat bogs do, so that for present purposes the question of source is of subordinate importance. At the same time, it is not without interest, for in a great proportion of cases, conditions favoring accumulation of coal followed those favoring deposition of clays. Firket's<sup>37</sup> observations have been cited frequently as showing that atmospheric water can convert shale into plastic clay and in support of the suggestion that underclays may be due to changes after deposit. Near Liège a shaft, 30 meters deep, reached an ancient mine which had been abandoned probably 700 years before. There the succession, descending, was Psammite, 0.95 m.; Gray plastic clay, 0.40 m.; Shale, not measured. The clay is very similar to the refractory clay of Ardenne. The psammite had given way, was broken and atmospheric water was admitted, which gave to that rock a brown tint while it changed the upper part of the shale into refractory clay. At another locality, the psammite in ancient workings had become sandy micaceous clay and the shale had become converted into black clay. Firket concluded that, under some circumstances, shale rocks may undergo considerable alteration *sur place*. The action of true mineral springs is not required to effect change of shale into clay, but infiltration of pluvial waters penetrating the ground across a small thickness of rocks may have an influence. It is unnecessary in that case to have the action extend over a long period in order to change 0.40 meter of shale into plastic clay, for not more than 700 years had passed since the ancient mines were abandoned.

<sup>37</sup> A. Firket, "Transformation sur place du schiste houiller en argille plastique," *Ann. Soc. Géol. de Belgique*, Vol. I., 1874, pp. 60-63.

The observations by Firket are not without interest but, as he recognized, they have little bearing on the matters at issue here. Shales oftentimes are merely laminated clays and lose their lamination when exposed to the atmosphere. There are many roads in the Appalachian basin which show deep through cuts in argillaceous shale. Less than a century, frequently much less than half a century has passed since the roads were constructed, yet the period has sufficed for conversion of the outcrops into plastic clay. But that is not the question. The Lower Kittanning coal rests on a bed of plastic clay, 10 to 20 feet thick, an excellent potters clay, used in manufacture of various wares along a line of more than 150 miles in Pennsylvania, Ohio and West Virginia; a flint clay at the base of the Allegheny, 5 to 25 feet thick, is utilized at many places along a line of fully 100 miles in Maryland and Pennsylvania. No condition such as that described by Firket seems likely to afford even a suggestion toward explaining the accumulation of such deposits, which, except as to thickness, are typical. Nor can one find sufficient explanation for the small proportion of iron in activities of plant life, since those could affect only the superficial portion. The features seem to be original in the mass and due to the work of atmospheric agencies prior to deposition. Long exposure of rocks causes deep disintegration and decomposition, as has been proved by Russell Crosby and Belt, already cited in another connection. The widely distributed Kittanning clay followed the Vanport subsidence, which had been preceded by a long period of quiet or of local elevation, during which deep valleys were eroded on the west side of Alleghania and, in an extended area, no new deposits were laid down. When the disintegrated materials were removed, the finest clays were deposited by themselves, carrying with them the impalpable humus of the soils. The strange irregularities, exhibited by beds in the closing portion of the Beaver, are evidence of a similarly long exposure for great areas and afford reason for applying the same explanation to the other great deposit. The condition may have been similar elsewhere and may account for clays under coal beds as well as at horizons where deposition of clay was not followed by conditions favoring accumulation of coal.

## THE COAL.

The passage from mur to coal is gradual at most localities ; but it appears to be rather abrupt where the seat is a sandstone or conglomerate. This latter statement is made with reservation, as the writer has had few opportunities to make determination, since coals with sandstone floors are seldom of economic importance within the areas which he has studied. No reference to the condition appears in the literature to which he has had access ; but the records of cores in the anthracite area lend countenance to the suggestion, for in many cases, a mere film of clay separates the coal from sandstone or conglomerate and the coal is good to the bottom. At some localities in the bituminous region, a coal bed is clean apparently to the contact with underclay, but in most cases the bottom coal is so impure as to be unmarketable. For the most part, one finds a transition layer, the *faux-mur*, between coal and clay ; it may be very thin or it may be several inches thick, and it may consist of inferior coal or of coaly shale.

In broad areas, where the *faux-mur* is distinct, there is, nevertheless, an abrupt separation of the coal bed from the underlying clay ; but this is not original, it is the result of disturbance. One finds this condition even in the western part of Pennsylvania and eastern Ohio, where the rocks vary so little from the original horizontality that the dips on the sides of the low anticlinals rarely reach half a degree and often for long distances are much less. Yet even there one finds that the coal has slipped under the pressure and that the contact between coal and clay is slickensided. This is the familiar condition everywhere, so that one seldom is able to determine the exact relation of coal to mur or the relation between plants of the mur and those of the coal. But the opportunity fell to the lot of Grand'Eury<sup>38</sup> during his study of the Loire basin. He says that in coal beds, at their mur and in their more or less shaly partings there are roots belonging to various species and that many a time he had

<sup>38</sup> C. Grand'Eury, "Du bassin de la Loire," *C. R. VIII<sup>e</sup> Cong. Géol. Int.*, 1900, pp. 531, 532 ; "Sur les conditions générales et l'unité de formation des combustibles minéraux de tout âge et de toute espèce," *Comptes Rendus*, Vol. 138, 1904, pp. 740-744.

seen rhizomas of ferns and creeping roots of *Cordaites* making part of the coal, thus binding the beds to the vegetation of the mur—which, as he says, contradicts one of his former determinations. The lower portion of the coal in such cases is irregular in structure but the passage from one grade of coal to the other is gradual and the coal throughout is composed of the same plants. His belief is that the running rhizomas at the bottom of the marsh have formed coal in place, along with the fossil humus, which he regards as formation of peat, by which the rooted plants were killed, the stems and adventive roots being found in the coal above.

The thickness of a coal bed is from a film to many feet. Definite coal beds, not more than 6 inches to a foot thick, sometimes mark a horizon over hundreds or even thousands of square miles. A thickness of more than 8 feet is unusual in the bituminous regions of this country but very much greater beds are reported from some fields in Europe. The Grande Couche of les Pegauds in the Commeny basin attains, according to Fayol, a maximum of 12 meters while the main bed of the other subbasin reaches, at one place, 20 meters. The vast deposits at Decazeville are in each case at least 70 feet thick near that city and apparently about 100 feet at a few miles south. Dannenberg gives the thickness of one bed in Saarbruck as 5 meters and of the great bed in the Upper Silesian field as from 10 to 20 meters. The Mammoth bed of the southern anthracite field attains a maximum of 114 feet at the easterly end, including only 9 feet of partings. In this case, as also in that of the great Reden bed of Upper Silesia, the enormous thickness is due to union of several beds by disappearance of the intervening rocks. Coal in any field makes up but a small part of the total section. In the middle division of the Saarbruck measures, there are said to be 132 coal beds, in all 32 or 33 meters thick, within a column of 850 meters; in the bituminous region of Pennsylvania, the column is somewhat more than 4,000 feet and contains perhaps 30 coal beds with total thickness of 110 feet.

## VARIATIONS IN STRUCTURE.

A coal bed is apt to vary rather abruptly in structure, local conditions having been as efficient during accumulation of coal as they are now during accumulation of peat. A coal bed may consist of two or more divisions, the benches or bancs, separated by partings, which are often more variable in thickness and composition than the coal itself. In some treatises, these benches are referred to as separate beds—and with good reason, as will appear after consideration of the varying character of the partings and the often contrasting composition of the coal in successive benches. Occasionally, however, definite structure persists throughout a considerable area. Thus the Pittsburgh bed, at the bottom of the Monongahela formation, shows roof division, overclay, breast-coal, parting, bearing-in-coal, parting, brick-coal, parting, bottom-coal.

This structure can be recognized in the northern part of the area along a west-northwest line of not less than 170 miles from the eastern to the western outcrop in Maryland, Pennsylvania and Ohio, exposures being practically continuous for 120 miles. It is distinct in an area on each side of the line not less than 40 miles wide for much of the distance and much wider on the eastern side. Yet even this remarkable bed, when traced beyond the limits given, shows that it too is variable. Bownocker<sup>39</sup> has made clear that on the western side, in Ohio, the structure changes abruptly at a little way south from the long west-northwest line. The change first appears in southern Belmont county, where the roof division disappears and the breast-coal becomes irregular. Within a few miles, the bed consists of coal, clay, coal, there being no recognizable trace of the upper 6 parts and the clay parting is often a foot thick, whereas in the typical section the partings are all thin, seldom more than half an inch. The condition, first observed in southern Belmont county, prevails southward on the western side for 90 miles. At some localities, the section resembles that seen farther north but analysis of the parts shows that they are not the same.

<sup>39</sup> J. A. Bownocker, Geol. Surv. Ohio, 4th Series, Bull. 9, 1908, pp. 10-12.

I. C. White<sup>40</sup> has given many measurements of the bed showing that similar changes are found in West Virginia along the eastern border, beginning at a few miles south from the Pennsylvania border. The Roof division is wanting almost at once, but that is due to erosion prior to deposition of the Pittsburgh sandstone, and at times one finds the bed complete where the roof was spared. At a little distance southwest, where the sandstone has thinned away, the changed section is distinct and the bed appears to be merely double. It is divided by "bone" or clay, 1 to 15 inches, and the benches vary greatly in thickness; at some localities the upper one has almost disappeared while at others the lower is almost wanting; here and there the bed has a section somewhat like that at the north but comparison of the parts shows that the resemblance is only apparent. The writer, nearly 40 years ago, thought that the change was merely apparent and that he could recognize all elements of the northern structure to a great distance south from Pennsylvania; but the many detailed measurements recorded by White make that position no longer tenable.

Study of measurements along the northern border of the bed prove a variability which was not considered important by the students who examined that area. W. G. Platt's<sup>41</sup> sections in Indiana county of Pennsylvania show that in the extreme northern outliers along the eastern side, the structure is clear, but the lower members are irregular, becoming indefinite at times, while the Breast-coal increases in importance. Measurements recorded by White and by Stevenson<sup>42</sup> in Allegheny and in northern Washington county show that in the outlying areas at the north, the structure is usually recognizable but that the bottom and brick are insignificant, the bearing-in not always distinct, while the breast, though variable, is the important portion. These changes are wholly in contrast with those already noted as occurring at the south in both Ohio and West

<sup>40</sup> I. C. White, *Geol. Surv. West Virginia*, Vol. II., 1903, pp. 168-190; Vol. II. a, 1908, pp. 659, 663, 665, and elsewhere.

<sup>41</sup> W. G. Platt, *Sec. Geol. Surv. Penn.*, Rep. *HHHH*, 1878, pp. 162-164, 27.

<sup>42</sup> I. C. White, *Sec. Geol. Surv. Penn.*, Rep. *Q*, 1878, pp. 152, 166, 177; J. J. Stevenson, *ibid.*, Rep. *K*, 1876, pp. 275, 277, 285; Rep. *KK*, 1877, pp. 313, 322.

Virginia and indicate a different history for the bed in the two regions, showing that coal accumulation persisted for a much longer period at the north than at the south. The conditions afford no little justification for the recognition of each bench as an independent bed. The irregularities of surface indicated by variations in the lower benches at the north as contrasted with the general regularity of the breast or upper portion show that in all probability the area of accumulation increased landward toward the north by advance of the marsh area. But increasing slate partings of extreme irregularity indicate sufficiently that small streams often flooded the area with muddy water.

The continuous area of the Pittsburgh coal bed was estimated by H. D. Rogers<sup>43</sup> at 14,000 square miles, the space embraced within the outcrop. I. C. White,<sup>44</sup> however, after study of oil-well records of West Virginia and Ohio discovered that the bed is wanting in a rudely triangular space within those states and that the available area is not more than 8,000 square miles. As the coal approaches the central area of fine sandstones and red muds, the structure becomes unrecognizable and the bed thins to disappearance. The constancy of the Pittsburgh coal bed is apparent rather than real.

Abrupt changes in thickness and structure are the rule in all coal beds. They are not startling in the bituminous region, except to those who have invested in mines, since the beds rarely exceed 10 feet; but they are very notable in the southern and middle anthracite fields. At one locality in the former, the Mammoth coal bed has 105 feet of coal in 114 feet of measures; at 8,246 feet toward the east it has only 42 feet in 49 feet; in both the coal is concentrated, there being but ten members in each section; but, within a short distance, one finds 40 feet of coal in 53 feet of measures and the section consists of 43 members.<sup>45</sup> Variations of this type are reported from all coal areas in the United States and they are commonplace in Europe.

<sup>43</sup> H. D. Rogers, "An Inquiry into the Origin of the Appalachian Coal Strata," *Reps. Amer. Assoc. Geol. and Nat.*, Boston, 1843, p. 446.

<sup>44</sup> I. C. White, "Stratigraphy of the Bituminous Coal Field in Pennsylvania, Ohio and West Virginia," *U. S. Geol. Surv. Bull* 65, 1891, p. 64.

<sup>45</sup> C. A. Ashburner, "The Geology of the Panther Creek Basin," *Sec. Geol. Surv. Penn.*, 1883, pp. 96, 98.

## BIFURCATION OF COAL BEDS.

Parallelism of coal beds seems to be regarded as a fundamental principle by some of those who have discussed the origin and formation of coal beds. It has been the subject of many papers in the United States, based on studies in the Appalachian and Mississippi coal fields. With one exception, the authors rejected the doctrine of parallelism, but most of them recognize that, in some extended areas there is parallelism along definite lines.

The partings between benches of coal beds are usually extremely variable but in some beds they show amazing persistence. The bearing-in bench of the Pittsburgh bed is from 3 to 6 inches thick and is bounded by partings which rarely exceed one half inch; yet these are present under more than 2,000 square miles, changing little in thickness or in composition. Ordinarily they consist of mineral charcoal and almost impalpable inorganic matter, but occasionally they have so little inorganic material that the coal appears to be continuous—but the partings are there and the benches retain their peculiarities. This persistence in character is, however, a strange exception and in most beds the variation is extreme.

The splitting or division of the Mammoth coal bed in the anthracite area has been proved not only by measured sections and drill cores but also by continuous workings, which often extend for many miles. In the northern part of the Eastern Middle, the Mammoth and the next bed below, the Wharton or Skidmore, are in contact, but within a short distance the parting has become 114 feet; in another part of the same field, the interval between the beds increases from 35 to 200 feet, the workings on each bed being continuous; the same beds are but 6 feet apart in the southern part of the Western Middle, but farther south, on the north border of the Southern, the interval increases gradually to 80 feet. The Mammoth itself divides. Near Shenandoah in the Western Middle it is a single bed, 40 to 60 feet thick, but within a short distance it is in 2 and then in 3 "splits" in a vertical space of 150 to 200 feet. In the Southern, the bed breaks up, reunites and breaks up again. Sometimes it is a single bed but within a mile it may be in 2 or 3 splits in a vertical space

of 175 to 214 feet.<sup>46</sup> The extreme variations in interval have been proved by continuous workings on the several splits. It is impossible to determine the relations of these changes in interval throughout the area, as erosion has been energetic in that contorted region and the coal beds remain only in a few deep troughs.

Illustrations are abundant in Europe. De Serres,<sup>47</sup> in his description of the little basin of Graissessac, says that the coal beds present great regularity as a whole and preserve their parallelism almost constantly. Nevertheless, one finds remarkable anomalies in some parts of the basin. Coal beds approach each other in some localities while in others they are far apart. At times the beds present the appearance of a fan, especially well shown in the mines of one concession; in some of those in another concession, coal beds 3, 5, 6, are almost united, though in other mines, No. 3 is most frequently at 30 meters from No. 4. When one considers that the whole basin is less extensive than the "outlying area" of Pittsburgh coal in Somerset county of Pennsylvania, he must be interested by de Serres's loyalty to the orthodox doctrine amid trying circumstances. Gruner<sup>48</sup> remarks that the parting of the Batardes coal bed is from 50 centimeters to 8 meters thick. In the middle portion of the Lower Saint-Etienne stage, beds 1, 2 and 4 coalesce with 3, which is very thick; but at times, 4 is separated from 3 by 24 meters of rock. Beds 3 and 4 are frequently united as are also 1 and 2. The area of this stage is little more than that of a township in one of the western states; according to the map, it does not exceed 40 square miles. Fayol<sup>49</sup> has shown that the Grande Couche of Commentry is one bed at the east side of the sub-basin but on the west side it is represented by 8 beds in a vertical section of more than 200 meters. Boulay and others have given illustrations from north France.

<sup>46</sup> The observations on which these statements are based have been summarized in "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. 17, 1906, pp. 219-221.

<sup>47</sup> (M) De Serres, "Des terrains houillers du département de l'Herault," *Acad. Sci. Montpellier*, Vol. I., 1850, p. 384.

<sup>48</sup> L. Gruner, "Bassin houiller de la Loire," Paris, 1882, pp. 212, 220, 225, 226.

<sup>49</sup> H. Fayol, "Études," etc., p. 22.

Dannenberg<sup>50</sup> states that the Zach bed of the Zwickau (Saxony) area is usually from 1 to 4.5 meters thick, but in the western part of the field it is represented by 2 beds, separated by 8 meters of rock. At Planitz in the southwest, the Planitzer bed is 10 meters thick and the partings are very thin; but these increase toward the north and the 3 benches are in a vertical space of about 70 meters. He gives illustrations of similar type from other coal fields. The familiar instance is that described by Jukes.<sup>51</sup> The Thick bed near Bilston has about 30 feet of coal in 12 to 14 benches; followed northward, the benches separate quickly, so that within 5 miles, one finds the 30 feet of coal distributed in a vertical section of 300 feet, the several benches being independent coal beds separated by shales and sandstones. The Bottom and the New Mine beds divide in like manner. Instances in other British fields have been described by Dugdale, Howell, Bolton and several other observers.

If one consider coal beds separated by considerable intervals he finds equally interesting variations. The Upper Freeport and the Pittsburgh are separated by 350 feet at the western outcrop in Ohio, but that interval increases gradually toward the east until in Indiana county of Pennsylvania it is 600 feet. The Pittsburgh and the Waynesburg are 166 feet apart at the northern outcrop in Pennsylvania, but that interval increases southwardly to more than 400 feet in northern West Virginia. The increase is regular in the thickness of intervening intervals between the Pittsburgh and Upper Freeport, for, throughout, the Ames limestone holds its place approximately midway between the coal beds; but no such regularity of increase is shown in the interval between the Pittsburgh and Waynesburg. An excellent illustration of this irregularity is shown by comparison of two sections given by W. G. Platt<sup>52</sup> from Armstrong county, Pennsylvania, which are as follows:

These measurements are about 18 miles apart and the interval between the Upper Freeport and the Lower Kittanning is practically

<sup>50</sup> A. Dannenberg, "Geologie der Steinkohlen Lager," 1911, pp. 211, 212.

<sup>51</sup> J. B. Jukes, "The South Staffordshire Coal Field," 2d ed., 1859, pp. 18, 19, 25, 26.

<sup>52</sup> W. G. Platt, Sec. Geol. Surv. Penn., Rep. H5, 1880, pp. 215, 288.

Upper Freeport coal bed.....	7	o	2	6
Interval.....	60	o	54	o
Lower Freeport coal bed.....	1	o	1	o
Interval.....	65	o	35	o
Upper Kittanning coal bed.....	1 to 12	o	1	o
Interval.....	45	o		
Middle Kittanning coal bed.....	4	o	117	o
Interval.....	25 to 40	o		
Lower Kittanning coal bed.....	3	o	3	o
Interval.....	33		25	
Vanport limestone.....				

the same in both, while the intervening intervals show notable variation. If one should group the sections given in Platt's report he would find that while the two coal beds preserve an approximate parallelism, the relations of the intervening beds would be indicated by lines describing very irregular waves. This portion of the Allegheny formation shows the same approximate regularity and the associated irregularity in other parts of the region.

The instance recorded by Jukes<sup>53</sup> has always been regarded as exceptionally perplexing. The "Roofs coal" of the Thick bed at Dudley rests on the bench below or is separated from it by, at most, 2 or 3 feet of clay; but in going toward Bilston, one finds the interval increasing, 0, 10, 37, 55, 128, 118 and at length, 204 feet near Bilston—these changes taking place within a mile and a half. Near Dudley one finds the Brooch coal at 95 feet above the "Roofs coal," known there as the "Flying Reed," and 108 feet above the Thick. But where the "Flying Reed" is 115 feet above the Thick it is only 30 feet below the Brooch; so that while the interval between Thick and Brooch has increased from 108 to 147 feet, that between Thick and Flying Reed intervening, has increased from 0 to 115 feet.

The condition is not confined to the Carboniferous. Lipold<sup>54</sup> found splitting of coal beds by no means unusual in the Triassic. At one locality, four coal beds were seen. The first and third converge in a westerly direction, the interval decreasing from 72 to 18

<sup>53</sup> J. B. Jukes, "South Staffordshire Coal Field," pp. 36-40.

<sup>54</sup> M. V. Lipold, "Das Kohlengbiet in der nordöstlichen Alpen," *Jahrb. d. k. k. Geol. Reichsanst.*, Band 15, 1865, pp. 85, 99-101, 109.

feet. The variation in position is in the lower or first bed, the place of the third remaining apparently unchanged. The third and fourth, on the contrary, converge toward the east and eventually unite. Bifurcation was observed in other beds and in some cases one or more subdivisions thin out to disappearance. The Cretaceous coals of the Rocky Mountain region show the same feature.

Some of the features so marked in coal beds are equally characteristic of peat accumulations. The description by Morton<sup>68</sup> may be cited as representative; the area has only a few square miles but the conditions are those observed on a grander scale in the great marshes of Holland and Belgium. At one locality Morton saw

Brown and gray estuarine silt .....	6	0
Upper peat .....	3	6
Gray estuarine silt .....	10	0
Lower peat, forest bed .....	2	0
Boulder clay .....	2	0

The peat and silt were deposited in depressions; they thin out in approaching the ridges. Sometimes the peat beds unite as they rise on the slopes and occasionally after uniting they become continuous with a surface bed which has never been covered. The lower peat shows many trees *in situ*. The peat about each tree is somewhat higher than that in the intervening spaces. The lower silt contains neither shells nor bones. The upper peat, 1 to 10 feet thick and at times divided by silt, contains no upright stems but there are prostrate stems with twigs and leaves as in a forest. The upper silt is sometimes 20 feet thick, but, there, the upper peat is absent and the silts are continuous. On earlier pages many citations were made, recording irregularities in peat deposits, such as variation in thickness, division or bifurcation of beds, disappearance of "splits" by thinning out, even the phenomenon of the "Flying Reed."

#### RELATIONS OF THE BENCHES IN COAL BEDS.

The total of coal in the separated splits may be greater or less than that in the undivided bed. The partings in the undivided bed

<sup>68</sup> G. H. Morton, "Further Notes on the Stanton, Ince and Frodsham Marshes," *Proc. Liver. Geol. Soc.*, Vol. VI., 1889, pp. 50-55.

may represent, in time-value, the intervening deposits where the splits are most widely separated—in which case the total thickness of coal may be approximately the same throughout. When a split loses thickness away from the place of union, it may be that subsidence began at some distance from that place and was, so to say, rapid; but where the split thickens, the subsidence was at first extremely slow, permitting accumulation to continue after it had ceased beyond the place of union. Some of the splits increase, others lose in thickness. A study of the benches in each split proves independent history.

One may not regard a coal bed as a single deposit, the result of consecutive deposition, broken only by pretty interruptions of clay or sand. It is the record of accumulation in a given area interrupted by longer or shorter intervals of no accumulation, which are marked by the partings. These intervals in one locality may be synchronous with continued accumulation in another. It is very evident that this accumulation did not begin simultaneously in all portions of the area now marked by a coal horizon and it is equally certain that its termination was not simultaneous throughout. Unquestionably the opening and closing of the work at any given horizon were embraced within a definite period, but one must recognize that only a very small part of the bed may be actually of synchronous origin throughout. Study of the benches of the Pittsburgh coal bed has led the writer to conclude that very little coal accumulated in northern Ohio and much of Pennsylvania until after a notable thickness had accumulated in southern Ohio and in West Virginia. The diminishing importance of the portion below the Bearing-in coal seems to indicate a northward advance of coal-forming conditions. It is equally clear that coal accumulation ceased after the Bearing-in within most of the southern portion, for the Breast is unimportant or absent, whereas it continued long time at the north, as appears from the increasing importance of the Breast in that direction. Changes of similar kind are shown by the Middle Kittanning or Hocking Valley coal of Ohio, which has been studied in detail throughout an area of more than 1,000 square miles, where it has great economic importance. Enough is known to make clear that,

in considering the problem of coal accumulation, one has not to deal with vast areas, since coal never was accumulating at any one time throughout a great basin.

#### RELATION OF COAL BEDS TO BLACK SHALE.

Coal beds vary in character; frequently coal passes gradually into black shale containing laminae of bright or dull coal; occasionally, the passage is almost imperceptible to the eye, the increase in ash causing no marked change in appearance. It is a common observation that, in the Coal Measures, black shale is almost certain to be replaced with coal somewhere. At the Uniontown horizon, in the Monongahela, one finds usually a thinly laminated black shale containing scales and teeth of small fishes and some laminae of coal; but at many localities within its area of several thousands of square miles, this becomes a coal bed which though impure is of local importance. Any coal bed is liable to show this change. The Buck Mountain bed, near the bottom of the Allegheny in the anthracite area, is worthless within a space of many square miles; the Mammoth bed degenerates westwardly and at times is little better than carbonaceous shale. Coal beds as they approach the border of their area are apt to show a greatly increased number of thin partings, usually mud but sometimes sand. Not rarely lenses of sand are intercalated, which may be of considerable extent. Such changes seem to indicate proximity to upland, whence streams came loaded with sediments. They suggest conditions like those which are seen within five or six miles west from New York, where one finds many times a small area of clean peat surrounded by impure material containing layers of mud.

The origin of the black shale is not always clear, but it is a sediment. The carbonaceous matter, in some cases, came in with the sediments as plant fragments, but in others it came rather from animal matter. An illustration of the former condition is found in the work by Scott,<sup>56</sup> who made dredgings in Lakes Ness, Oich and

<sup>56</sup> T. Scott, "The Lochs of the Caledonian Valley," *Scot. Geogr. Mag.*, Vol. VIII., 1892, pp. 94, 95.

Lochy for the Fishery Board of Scotland. In Ness, the dredge was filled with fine mud containing fragments of peaty matter and pieces of partially decayed wood. Some exuviae of entomostraca were present but no living specimens were observed. The same condition was found in the other lakes where no attempt was made to determine the thickness of the deposit. In these lakes, the water is free from mud and is dark brown, owing to dissolved organic matter from peat. The streams descend from the Highlands, but the region is protected from erosion by a cover of peat, so that only very fine silt is brought down. The brown waters pass out to the sea and the dissolved materials are not precipitated in the lakes.

The presence of vegetable remains along with those of marine animals in many black shales is by no means proof that the water was shallow nor is the association in any sense evidence that the water was deep. The observations by Agassiz<sup>67</sup> have been cited many times in this connection as though they contain the final argument. In reference to dredgings in the Caribbean sea he says, that the contents of some of the trawls would have puzzled a palæontologist; there were deep water forms of crustaceans, annelids, fishes, echinoderms and sponges, mingled with mango and orange leaves, branches of bamboo, nutmegs and land shells, both animal and vegetable forms being in great profusion; so that it might be difficult to decide whether one were dealing with a land or a marine fauna. Such a trawl from a fossil deposit would naturally be explained as representing a shallow estuary surrounded by forests; yet the depth may have been 1,500 fathoms. The large quantity of vegetable matter, thus carried out to sea, seems to have a marked effect in increasing locally the number of marine forms.

Whether or not any palæontologist would have reached the conclusion suggested for him by Agassiz is scarcely open to dispute; the palæontologist's answer to the query would be unequivocal and thoroughly emphatic. Commingling of marine and land elements occurs in shallow as well as in deep portions of the Caribbean, with

<sup>67</sup> A. Agassiz, "Three Cruises of the *Blake*," *Mem. Mus. Comp. Zool.*, Vol. XIV., p. 291.

the distinction that in the latter there are the forms known to be characteristic of deep sea zones only. But no such problem as that imagined by Agassiz presents itself in the Coal Measures—though there are those who believe the contrary. Respecting the marine forms of the Coal Measures time one may assert positively nothing beyond the fact that they are closely related to marine types. There is no evidence to prove that they preferred deep water but there is abundant evidence to show that they had no objection to dwelling in shallow depths; it is sufficiently clear that limestones carrying the typical forms were deposited at many localities where every feature indicates shallow water and close proximity to a shore. This matter has been considered in an earlier part of this work, but it may be well to present additional notes here.

D. White<sup>58</sup> during the summer of 1912 found evidence of presumably shallow water deposition of some Coal Measures limestones in Oklahoma; Udden has described a brecciated marine limestone near Peoria, Illionis. Ashley<sup>59</sup> found near Merom in Indiana 2 to 8 feet of conglomerate, consisting of shale, sandstone and coal pebbles, bedded in calcareous matter and resting on 2 to 4 feet of marine limestone. This conglomerate underlies the great Merom sandstone. A stream flowing over the outcrops entered the sea and dropped its load of coarse material into the unconsolidated upper portion of a limestone containing *Productus* and other marine types. As the conglomerate is coarse, it must have been dropped at once when the stream entered a body of water. The Ames limestone is impure, conglomerate but fossiliferous at a locality in Meigs county of Ohio, as recorded by Condit; on the extreme western border in Muskingum county of the same state the Ames is shaly and coarse grained, showing none of the characteristics observed farther east, but it is fossiliferous; in Carroll, on the northwest border, that limestone on the extreme outcrop is very impure, coarse grained and very like sandstone; at a short distance farther east it is more like limestone but at a mile farther it is earthy and disintegrates on exposure. At these localities, one is very near the original shore, where the water

<sup>58</sup> Letter of October 25, 1912.

<sup>59</sup> G. H. Ashley, "Coal Deposits of Indiana," p. 908.

was shallow and far from clean, but the characteristic fossils persist to the last exposure of the horizon. Bownocker has noted a number of localities in Meigs, Gallia and Lawrence counties of Ohio, all on the western border, where this limestone is impure, argillaceous, ferruginous or sandy, yet the fossils persist. I. C. White found the same conditions along the northern border in Pennsylvania. Hennen<sup>60</sup> reports that in Harrison county of West Virginia, where one approaches the southern limit of the Ames limestone, the rock is an impure limestone, often represented only by dark limy shale but always containing the same marine fossils. The Conemaugh formation has other marine limestones which are brecciated at numerous localities. In some cases the shells are broken as on a shore.

#### THE OCCURRENCE OF CANNEL.

The cannels and bogheads differ from true coals not merely in structure and composition but also in their mode of occurrence. Cannel is invariably a local deposit, in the extreme sense of the term, though conditions favoring its formation existed more frequently at some horizons than at others. Many of the small isolated basins in Iowa, Missouri and even in Pennsylvania contain only impure cannels, but ordinarily the mineral forms part of a coal bed, the relation being intimate. Invariably, the deposit is saucer-shaped, as though occupying a depression in vegetable matter previously accumulated. White<sup>61</sup> has described a cannel of much commercial importance, though it is confined to only one estate; the mass has a maximum thickness of 12 feet and thins away to nothing in all directions. The changes are exhibited in extensive workings. Platt<sup>62</sup> examined, in Armstrong county of Pennsylvania, three disconnected patches of cannel at the Upper Kittanning horizon. The space between these is occupied by ordinary coal. In each, the cannel is from 0 to 8 feet thick; the bottom bench of the coal bed is bituminous and it is depressed with the thickening cannel, the slope of the

<sup>60</sup> R. V. Hennen, W. Va. Geol. Surv., County reports, 1912, p. 251.

<sup>61</sup> I. C. White, Sec. Geol. Surv. Penn., Rep. Q, pp. 213, 232, 258, 259, 268.

<sup>62</sup> W. G. Platt, *ibid.*, Rep. H5, p. 176.

upper surface being from 5 to 22 degrees; but the top bench, also bituminous, rests on the horizontal surface of the cannel and is regular throughout, as is also the roof, both showing only the insignificant dip characterizing the region. In Pennsylvania, one rarely finds cannel at the bottom of a coal bed, but that condition occurs occasionally in West Virginia and it is not infrequent in Ohio. Some coals of the Beaver within Ohio and Kentucky have considerable areas of cannel and are spoken of as cannel beds; but even in those the features are the same as in others, excepting as to extent. The story is the same in all areas. Hull has shown that the celebrated Wigan deposit in Lancashire is saucer-shaped; Green found the same condition in the Yorkshire deposits; David, Mackenzie and Wilkinson have recorded many observations showing that the Kerosene shale of New South Wales has similar distribution. The phenomena are familiar in modern swamps.

#### DISTRIBUTION OF COAL IN RELATION TO THE ACCOMPANYING ROCKS.

The distribution of coal seems to be related in some way to the character of the associated rocks. In the southern and middle anthracite fields, the coal beds are thick at the northeast, where coarse rocks most abound, and become unimportant at the west, where coarse rocks are less abundant. In the Pottsville of those fields, there are thick coals with pebbly rock above and below, though in most cases there is some shale, often very thin, above or below the coal. In the bituminous region, coal beds of the Allegheny and higher formations appear to have accumulated chiefly on the borders of that region—not as continuous bands, but at definite horizons. They thin away and the horizons become indefinite as one approaches the central area, in which fine materials prevail; yet even there, coal was formed in thin irregular deposits at widely separated localities; and these petty accumulations seem to be at or near horizons which are well defined elsewhere. Coal-making conditions did not exist for any considerable period or in any considerable area within the region of fine-grained rocks.

The same relation has been observed in other countries.

Phillips,<sup>63</sup> referring to his studies in Yorkshire, states that toward the southwest the limestones thicken, while sandstones and shales become thin. The sandstones thicken toward the north, while shales thicken toward the west, in which direction certain sandstones and limestones vanish. With those sandstones, the coals also vanish. Where the sandstones thicken and grow numerous, toward the north, in which direction the limestones change from an undivided mass to many members, the coal beds augment in number and in thickness. A similar condition is apparent in eastern Oklahoma.

Coal beds seem to be wholly wanting in the Mississippi limestones of the Appalachian basin. Their absence from this mass, at times more than 2,000 feet thick, including the calcareous shales, can hardly be due to lack of vegetation on the land, for the underlying Pocono or Logan sandstone and shales show definite coal beds from central Pennsylvania to Wythe county of Virginia, a distance of not less than 400 miles; while the sandy division of the Chester, equivalent to the highest part of the Mississippian, contains thin coal beds at many places west from the old Cincinnati land. The writer has not been able to make sufficient study of conditions elsewhere to justify him in offering a generalization; but in the Appalachian basin, every observation indicates that conditions favoring deposition of marine limestone or of fine detritus in extended areas are not favorable to the accumulation of coal beds.

#### MACROSCOPICAL STRUCTURE OF COAL IN BEDS.

The several benches of a coal bed may show marked differences aside from those already mentioned. The coal from one may be impure, containing large percentage of ash or sulphur; that from another may be hard, breaking into more or less regular blocks; that from a third may be brilliant, tender; that from a fourth may be prismatic, the rude prisms or columns being readily separable with the fingers; that from a fifth may be a solid coal, yet not hard enough to bear rough handling; while any one of the five benches may show saucer-shaped inclusions of cannel. These variations are shown in

<sup>63</sup> J. Phillips, "A Treatise on Geology," new ed., London, 1852, Vol. I., p. 190.

the Pittsburgh coal bed and are illustrative of those shown by nearly all beds. They are associated with equally marked chemical differences, which will be considered on a later page.

The coal in all benches has a laminated structure, due perhaps in some cases to pressure but in others to some other cause. The writer has traced laminæ, which tapered to nothing in each direction along an entry; whether or not this is characteristic, he cannot say. Any one who has attempted to determine this matter in a coal mine must have recognized that the intense application required should be devoted to something more important. H. D. Rogers concluded that in pursuing any brilliant layer, not more than one fourth of an inch thick, one may observe that its superficial extent is too great to permit the supposition that it had been derived from the flattened trunk or limb of any arborescent plant. It is certain, however, that pressure cannot account for the alternation of brilliant or glance laminæ with those of dull or matt coal, which one finds almost invariably. Usually these layers are very thin, but in many instances they are several inches thick. Sometimes this lamination seems to be due to the presence of mineral charcoal, which covers every surface obtained by splitting, but at others the charcoal is clearly without influence, for it lies in all directions. This mineral charcoal is a common constituent of all the fuels from anthracite to peat, but it is not an essential constituent, for layers of glance several inches thick have been found without it and Orton<sup>94</sup> has described a coal bed of workable thickness which shows no trace of it.

Fragments of plants, sometimes large, occur in coal. Occasionally they have been converted into fusain but more frequently they appear as glance coal,—though even these occasionally enclose more or less of the charcoal. Ordinarily they are flattened, the interior having disappeared while the cortex remained to be converted into glance. At times, they are merely impressions on the apparently structureless mass of coal, recalling the conditions observed in many peat deposits, where the great bulk of vegetable material has been changed into the flocky ulmic mass, while enclosed stems of trees,

<sup>94</sup> E. Orton, "Mines of Muskingum and Licking Counties," Geol. Surv. Ohio, Vol. V., 1884, p. 881.

changing more slowly, are still recognizable. These stems are found in coals of all types and they are associated very commonly with leaves.

Lesquereux<sup>65</sup> asserted that *Stigmara* occurs as frequently in American as in European coals. In Greenup county of Kentucky, he saw a cannel, 4 feet thick, containing such abundance of *Flabellaria* and *Stigmara* that he believed the coal to be composed of those plants. In another, he found great numbers of *Stigmara* and beautiful impressions of *Lepidodendron*. Coal beds I. and XII. in western Kentucky are composed in places of flattened *Stigmara*, *Calamites* and *Sigillaria* with, in I., *Lepidodendron*. The Breckenridge deposit is rich in fine impressions. Long ago, E. B. Andrews, in writing of the Ohio and Kentucky cannels, said that *Stigmara* seemed to revel in the ooze which became cannel. Orton<sup>66</sup> says that the upper or bituminous portion of the Upper Mercer coal bed contains "the most beautiful specimens of *Stigmara*; nearly every mine car contains what would be a prize in a geological museum." These retain their lateral appendages. Many incidental, possibly accidental references are found in other geological reports, but they give no details. At the same time, they suffice to show that remains of trees are recognizable in the coal of very many beds and that *Stigmara* is not confined to the lower part of the deposit, but occurs in all portions in bituminous as well as in cannel.

Dawson<sup>67</sup> examined carefully every coal bed exposed in the long South Joggins section. Many deposits of inferior coal in Divisions 3 and 4 are composed of recognizable leaves and stems and there are beds of clean bright coal containing *Sigillaria*, *Cordaite*s and other forms. The stems are almost invariably prostrate, but in one coal bed he saw a coaly stump and an irregular layer of mineral charcoal, "arising apparently from decay of similar stumps." In another bed, composed of prostrate *Sigillaria* with *Cordaite*s, etc., he found a

<sup>65</sup> L. Lesquereux, "Geology of Pennsylvania," 1858, Vol. II., p. 841; Third Rep. Geol. Surv. Ky., 1857, pp. 529, 532, 548; Fourth Rep., *ibid.*, 1861, pp. 342, 349, 368, 379, 405, 412.

<sup>66</sup> E. Orton, Jr., Ohio Geol. Surv., Vol. V., 1884, p. 850.

<sup>67</sup> J. W. Dawson, "Acadian Geology," 2d ed., pp. 159, 162, 168, 171, 173, 174, 190, 438.

stump as mineral charcoal, while, in another, a trunk was seen, reduced to little more than coaly fragments, surrounded by a broken, partly crushed cylinder of bark. His study convinced him that the bark of *Sigillaria* and allied plants gave the bright coal, while wood and bast tissues yield mineral charcoal, the dull coal coming from herbaceous plants and mold.

Goeppert<sup>68</sup> found in the coal itself not only the plants which characterize the accompanying shale, but also many other species, especially of *Sigillaria*. The coal contains, in areas studied by him, *Stigmaria*, *Sigillaria*, *Caulopteris*, *Calamites* and other types forming stratified beds, 30 to 40 feet thick. Of the stems, only the rind remains and that is pressed flat. Where the chemical change was long continued, the features of the rind disappeared and the coal became structureless; but he often saw structureless coal pass into that with well-defined structure. At some localities the coal is composed of Araucarian stems and *Stigmaria*, while at others *Lepidodendron* is so abundant that one can hardly find a piece not containing that plant.

Grand'Eury<sup>69</sup> says that *Stigmaria* is very abundant in the coal of Rive-de-Gier; that *Cordaites* forms the greatest part of the coal in mines near Saint-Chaumont and in those of the Chazotte; it seems to be almost the only form in the coal of Tartaras, but is associated with ferns at Peron Midi and at Gandillon. At some places near Saint-Etienne, *Sigillaria* makes up practically whole beds of coal. Conditions are similar in other parts of Europe. He cites von Ettinghausen, who states that, at Radnitz, the coal-forming plants are *Sigillaria* and *Stigmaria*, with *Lepidodendron* and *Calamites*, but the latter two as well as the ferns are unimportant. Grand'Eury found similar conditions at Eschweiler, Wurm, Essen and Saarbrück; Geinitz called the Plauen deposit, *Calamites* coal. But Grand'Eury emphasizes the fact that a coal bed has not been formed by any single kind of plant. He remarks that occasional specimens of stems are found, converted into carbonized wood, showing the

<sup>68</sup> H. R. Goeppert, "Prize Essay," 1848, pp. 69, 70, 72-75, 276, 277, Pl., Fig. XVI.

<sup>69</sup> C. Grand'Eury, "Flore carbonifère du Département de la Loire et du Centre de la France," Paris, 1877, pp. 153, 168, 212, 213, 259, 396-398.

cortex and the intra-cortical fusain, which is finer than that from the wood.

Fayol<sup>70</sup> learned to distinguish coal made from *Calamodendron*, *Cordaites* or ferns as readily as he could distinguish a piece of beech from one of fir. He recognized these types first in isolated laminæ, but afterwards in brilliant laminæ occurring in the thickest and purest parts of the Grande Couche. He saw tree trunks in Commentry, some buried in the lower benches of the coal and others passing from the coal into the overlying shale. One fourth of one percent of the trees in the coal are vertical, an equal proportion are inclined and the others are prostrate. Few trunks in coal are cylindrical; where such stems occur, one can prove usually that one of the extremities is in sandstone.

David,<sup>71</sup> in describing deposits of Kerosene shale, reports that in one mine at the end of Megalong ridge, the shale contains erect stems of *Vertebraria*; in another, prostrate stems; in a third are flattened stems or "barky casings of plants turned into bituminous coal, over four inches in width." David saw many vertical and prostrate stems of *Vertebraria* in the Shale at a locality in Cook county. Wilkinson saw at Joadja creek impressions of *Vertebraria* lying horizontally in the Kerosene shale as well as numerous vertical stems of the same plant, whose lustrous, bright substance is in striking contrast to the dull luster of the enclosing shale. Nathorst found stems of *Bothrodendron* in the Devonian coal of Bear island and stems are present in many brown coal deposits as well as in the peats of modern bogs.

#### FOREIGN BODIES IN COAL.

The presence of tree stems in coal is normal; but the coal often contains what may be regarded as foreign bodies.

Nodules of calcareous clay-iron stone are familiar objects in coal beds as well as in the Coal Measures shales. They are from mere specks to balls a foot or more in diameter. Occasionally they

<sup>70</sup> H. Fayol, "Études," etc., pp. 135, 196, 198, 206, 207.

<sup>71</sup> T. W. E. David, Dept. Mines New South Wales, Rep. for 1890, 221-224; C. S. Wilkinson, *ibid.*, p. 208.

are rudely spherical but for the most part the shale is irregularly oval and occasionally even plate-like. When enclosed in coal beds, the laminae are displaced about them as though the final compression had taken place after formation of the nodule; and this feature is as characteristic of coals which have not been distorted as of those which have been folded. The nodules are often fossiliferous, containing marine shells at times but land forms and plants at others—as those obtained at Mazon creek in Illinois, in which are remains of many animals as well as plants, all marvelously well preserved. Such nodules have been found in the Devonian, for Nathorst<sup>72</sup> obtained some from shales of that age in Spitzbergen; *Lepidodendron* and apparently *Bothrodendron* were recognized in several of them, while others contain remains of fishes.

More than 80 years ago, calcareous nodules more or less ferruginous, occurring in the roof and coal of a thin bed in the Lancashire coal field, attracted Binney's attention and were made the subject of a memoir by Hooker and Binney. Since that time, such nodules have been discovered in many lands and have been investigated by students in Europe. In this summary, reference is made only to some of the later publications.<sup>73</sup>

Coal balls were supposed for a long time to be confined, in England, to a single horizon, the thin Lancashire coal bed known as the Mountain Upper Foot. This, in the Lower Coal Measures, is at a variable distance above the Ganister coal bed, one of the most per-

<sup>72</sup> A. G. Nathorst, "Zur palaeozoischen Flora der arktischen Zone," *Hand. K. Svens. Vetén-Akad.*, Band 26, No. 4, 1904, pp. 11, 13.

<sup>73</sup> D. Stur, "Ueber die in Flötzen reiner Steinkohle enthaltenen Stein-Rundmassen und Torf-Sphaerosiderite," *Jahrb. d. k. k. Geol. Reichsanst.*, Vol. XXXV., 1885, pp. 628 et seq.; A. Strahan, "On the Passage of a Seam of Coal Into a Seam of Dolomite," *Quart. Journ. Geol. Soc.*, Vol. LVII., 1901, pp. 297-304; H. B. Stocks, "On the Origin of Certain Concretions in the Lower Coal Measures," *ibid.*, Vol. LVIII., 1902, pp. 46-58; M. C. Stopes and D. M. S. Watson, "On the Present Distribution and Origin of the Calcareous Concretions in Coal Seams, known as 'Coal Balls,'" *Phil. Trans. Roy. Soc., Ser. B*, Vol. 200, 1908, pp. 167-208; W. Gothan und O. Hörich, "Ueber Analoga der Torfdolomite (Coal Balls) des Carbons in der rheinische Braunkohle," *Jahrb. k. preuss. Landesanst.*, Band XXXI., Teil II., 1910, pp. 38-44; C. Barrois, "Étude des strates marines du terrain houiller du Nord," 1<sup>re</sup> Partie, 1912, pp. 4, 9, 38, 62.

sistent members of the column. The Ganister, when separated by several yards from the upper Foot, contains no balls; but when the parting is only a few inches, the balls are in both beds. There is no regularity in the distribution. The Hard coal bed, near Halifax in Yorkshire and belonging apparently at the same horizon, also contains similar balls. These concretions have a slickensided surface and the coal laminae curve around them; occasionally a faulted specimen is found. In size they vary from an inch to a foot or even more—one, near Shore, weighs 2 tons and replaces the coal from roof to floor. These balls in the coal contain plant remains in condition of remarkable preservation.

The roof shale of this coal bed carries abundant remains of marine animals along with much fragmentary plant material. "Bullions," "baumpots" or "Goniatite nodules" occur in this shale and are as characteristic of it as the coal balls are of the coal. These roof balls enclose shells with which there are often bits of plants, rarely well preserved but at times admitting of generic determination. *Sphaerosiderites*, answering to the English roof balls or bullions, have been found within the Nord (France) basin in marine shales, sometimes resting on thin coals. They, like the English balls, contain *Goniatites*, *Productus* and other forms; but Barrois does not note the presence of similar concretions in the coal.

*Sphaerosiderites* were obtained at collieries in the Ostrau coal field from the roof shale of the Heinrichs and Coaks coal beds; in each case the shale is marine. The balls from the higher shale are occasionally fossiliferous but those from the roof of the lower bed seem to be without fossils. The lower part of this shale, however, is crowded with small balls of pyrite, many of which are fossiliferous, while many shells in this portion have been replaced with pyrite. The balls, for the most part, are small, very irregular in form and often are polished, so that they might easily be mistaken for erratics. Sometimes several are united but ordinarily they are separate and are scattered throughout the shale. They are encrusted with powdery matter, one to two millimeters thick, which is removed readily by washing. When exposed to the weather, their concretionary structure soon becomes apparent.

The Coaks bed contains great numbers of coal balls or plant-sphaerosiderites; Stur obtained several hundreds in a large block of coal shipped to him from the mine. These are especially abundant in the upper bench and on the west side of the area, where the roof balls also are most numerous. The remains of plants in the coal balls are always well-preserved but those in the roof balls are in bad condition.

The roof balls, according to Stopes and Watson, have from 4 to 6 per cent. of clay, whereas the coal balls have often no more than a trace. Stur has given two analyses of those from the roof, which are quite dissimilar:

Carbonate of calcium .....	61.43	29.01
Carbonate of magnesium .....	2.86	4.33
Carbonate of iron .....	16.13	25.09
Carbonate of manganese .....	1.73	—
Sulphide of iron .....	—	6.45
Clay .....	2.49	2.22
Insoluble matter .....	13.03	30.20
Water and loss .....	2.33	2.70

The coal balls show extreme variations in some constituents. According to Stopes and Watson, those from Bacup are chiefly dolomite; whereas several of those from Shore show very little magnesia, and only 2 of the 5 specimens analyzed have more than 5 per cent. of carbonate of magnesia. Stocks analyzed two from Yorkshire localities, which gave

Carbonate of calcium .....	64	82
Carbonate of magnesium .....	2	0.75
Sulphide of iron .....	21	12

with small per cent. of sulphate of calcium, silica, clay and organic matter. Sometimes the nodules contain pieces of fossilized wood which are large enough for study. They also show much variation, 4 specimens giving

Carbonate of calcium .....	86	24	87	49
Carbonate of magnesium .....	4	2	3	6
Sulphate of calcium .....		14	1	9
Sulphide of iron .....		49	5	24

with other constituents in small proportion; the fossilized wood like the mass of the concretion is composed chiefly of carbonate of calcium and sulphide of iron. The analysis of Stur's specimen differs somewhat; it is

Carbonate of calcium .....	56.52
Carbonate of magnesium .....	10.02
Carbonate of iron .....	15.60
Clay .....	0.89
Insoluble matter .....	0.17
Organic matter, water, loss .....	16.80

but, like the other analyses, it shows the great freedom from clay and silica, which are so important in roof balls. This difference led Stur to distinguish the latter as clay-sphaerosiderites.

Except at the Bacup locality, dolomite is not the important constituent of the coal ball. Strahan's notes respecting the Wiral colliery in Cheshire seem to have some bearing on this matter. The coal there was 4 feet thick and of good quality where opened; but within a short distance bands of stone, 1 to 10 inches thick, appeared, some of them consisting of spherical pellets. Within 250 yards, the coal was replaced with this rock, but the roof and floor remained unchanged, save that the former had become reddened—this change, however, being unrelated apparently to that in the coal. The rock is black and hard, but weathers gray; the structure is pisolitic and the concretions are sometimes united, at others independent and separated by coaly matter. They consist of dolomite with some coaly material, iron, silica and clay. Some fragments are composed of small masses or irregular crystalline layers, separated by fine mud containing quartz and flakes of mica; while others, consisting partly of woody tissue filled with dolomite, may be regarded as wood fragments, impregnated with and cemented by dolomite. When this dolomite has been removed by acid, a copious residue of carbonized fibers is obtained.

These balls or sphaerosiderites are concretions formed in the coal and shale after the deposits had been made but before consolidation. The laminæ of coal and shale curve around them and some of the concretions were broken during the later compression.

Green<sup>74</sup> in describing the Yorkshire roof balls says that the *Goniatites*, *Aviculopecten* and other shells enclosed are not flattened as are those in the shales. The plant material in the coal balls is in wholly uncompressed condition, so that the minutest details of structure can be recognized—as one may see by consulting Williamson's memoirs in the *Transactions of the Royal Society*. Stur found the stems of plants not only uncompressed but also, in some cases, not wholly decayed, so that the concretions were formed before the chemical change had been completed. Stopes and Watson were convinced that they had traced a stem continuously from one coal ball into another; Wild says that the Lancashire "bullions," composed of fossil wood, occasionally show rootlets working their way through the decaying wood, separating the fibers which now surround them. But vegetable fragments in roof balls are different; as Stur remarks, they are coaled and evidently much changed; they tell little of relations and less of structure.

But coal balls are not confined to the Coal Measures. Gothan having noted that the localities, where the balls had been obtained, were all within paralic basins set himself to discover them under other conditions. Petrified stems are common in Tertiary beds, where, as deposition centers in brown coal, they have given opportunity for concentration. Such silicified or at times pyritized stems occur frequently in the Halle brown coal and in the Rhenish brown coal one finds the well-known oolite wood. But these are not wholly analogous to coal balls, which are bits of petrified peat, penetrated at times by roots of vegetation growing above. In searching the survey collections at Berlin, Gothan found a piece of brown coal from the Donatus mine near Cologne, which contained spherules of carbonate of iron, the same as the material of the oolite wood. Deposition had not been confined to the wood but had reached into the actual peat. Specimens were procured from Flügel, who had mapped the area, and they proved to be part of the bed, replaced with material like that of the plant-balls described by Stur. Gothan suggests the name of Torf-Dolomite. Microscopic examination by Hörich showed the close resemblance between these forms and the coal balls. As a

<sup>74</sup> A. H. Green, "The Geology of the Yorkshire Coal Field," p. 108.

rule, however, the plant remains are less well preserved than in the coal balls; they are so disintegrated that in many cases they are not identifiable. Roots are best preserved, probably because they entered when the surrounding mass had already become peat. They show no trace whatever of compression. Some fragments of stems have great lacunæ, indicating that they are of plants belonging to a moist habitat. The great variety in the plants suggests that the deposit is a typical Waldtorf, which accords with the belief that the brown coals were deposited as Waldmoors.

This conclusion is very similar to that reached by Stopes and Watson, who recognize a swamp vegetation in the coal balls, as, indeed, Stur had done long before. Stur had noted the difference in condition of the vegetable material in the two types of balls, and this difference is emphasized by Stopes and Watson. Scott had observed that the roof-ball flora, though of Lower Coal Measures age, has no slight resemblance to that of the Permian, and those authors think that it is comparable to an upland flora, so that it may be more characteristic of the widespread vegetation than is that of the coal balls.

Dolomite, calcite and carbonate of iron are not the only minerals replacing plant material in concretionary fashion. E. B. Andrews and Lesquereux found wood in coal wholly replaced with sulphide of iron, the form being uncompressed; but no microscopic study was made to ascertain whether or not any trace of structure remained. The Grand'Croix flints are of the same type as the coal balls and they yielded interesting results to Renault, who recognized that they are petrified peat. Near Salem in Oregon there are fossil stems, which show all gradations between lignite and silica within a few feet.

The source of the material forming the balls has been subject for speculation. Balls from the more celebrated localities are in coal beds with marine deposits as the roof. Binney thought the shells provided the material, but objection was made that the shells are not dolomite and that one should look to sea-water as the source. As the roof shales in the Coal Measures localities are marine, sea-water must have covered them all alike; yet in Lancashire, the balls are dolomite at Bacup, whereas at Shore only one specimen showed

as much dolomite as calcite while in three others dolomite is absent or insignificant. Dolomite is unimportant in the Yorkshire balls, but it is in large proportion in Stur's specimen, while it is shown in small proportion by the roof balls of the same area. It would appear that sea-water can hardly be regarded as the source, in view of the marked variations found within short distances. And this suggestion is strengthened by the fact that Gothan's Torf-dolomite closely resembles in composition the coal balls described by Stur.

It may be preferable to seek the source in the materials themselves, the inorganic matter forming the shales and the ash of the coals. Carbonate of magnesium is found in most of the coals as well as in peats and it is often an important constituent of wood ash. The varying proportion in the balls may indicate merely a varying proportion in the shales, depending on the nature of the rock whence they were derived. And this seems to be reasonable, when one considers the composition of limestones. McCreath<sup>75</sup> made many analyses for the Pennsylvania survey, which illustrate the conditions. The Vanport limestone of the Allegheny formation is of marine origin throughout and is one of the widely extended deposits. Carbonate of magnesium rarely exceeds 2 per cent. and very often is less than 1 per cent.; but on the northern border, where it extends into old valleys and is mingled with land material, the percentage increases, attaining 6.65 at one locality. A similar change appears in the Ames limestone. In Harrison county of West Virginia, that limestone is approaching its southern limit as a marine deposit. It contains in its upper division 25 per cent. of alumina and in the lower, 18 per cent. of silica. The influx of land material is very marked, though the marine fossils persist in great numbers; the carbonate of calcium varies from 40 to 48 per cent. and carbonate of magnesium from 15 to 21 per cent.<sup>76</sup> McCreath's analyses of Monongahela and other limestones, which from their relations must be regarded as non-marine, show that in some cases they are markedly dolomitic and with few exceptions they have a

<sup>75</sup> A. S. McCreath, *Sec. Geol. Surv. Penn., Rep. MM*, 1879, pp. 281-362; *Rep. M3*, 1881, pp. 79-94.

<sup>76</sup> B. W. Hite, in *West Va. Geol. Surv., County Reps.*, 1912, p. 251.

large percentage of insoluble residue. Lesley's<sup>77</sup> study of the elaborate series of analyses, showing composition of the 115 layers of limestone exposed opposite Harrisburg, led him to conclude that in this exposure two types of deposits alternate; one is of limestone, with 2 to 3 per cent. of carbonate of magnesium and 1 to 2 per cent. of insoluble matter; the other, a dolomitic limestone, with 26 to 35 per cent. of carbonate of magnesium and the insoluble matter is from 7 to 15 per cent. The large percentage of silicate of aluminum is always in the dolomitic beds. The layers analyzed are from a few inches to 8 feet thick, are distinctly separate and the extreme variations of composition are often in direct contact. One who reads carefully the whole of Lesley's discussion is compelled to recognize that the differences are original, not secondary, that they are due to conditions in the drainage area, not to change in composition of the water in which they were deposited.

The replacement described by Strahan may be due to mineral springs as are the flints of Grand'Croix.

Remains of animals may be regarded as foreign bodies. Cannel often contains abundance of such remains. In such localities, on both sides of the Atlantic, it has been a rich mine for the palæontologist. Marine shells have been found in ordinary coal. The Harlem coal bed, underlying the Ames limestone, has marine forms in its topmost layer at a locality in Ohio as well as at one in West Virginia and Raymond found a marine shell in the Kittanning coal at a locality in Ohio. Remains of higher animals occur in coals of later age. Anker<sup>78</sup> examined a brown coal of Molasse age in Styria, which so closely resembles black coal that is distinguishable only by its geological position and its occasional woody structure. Bones are present in 3 layers, where they are very numerous, though fragmentary. A jawbone, retaining the teeth, was recognized as belonging to *Hyena*. Bones of mammals occur frequently in modern swamps.

<sup>77</sup> J. P. Lesley, Rep. *MM*, pp. 360, 361.

<sup>78</sup> Anker, "The Occurrence of Bones of Animals in a Coal Mine in Styria," *Proc. Geol. Soc. London*, Vol. I., 1834, p. 467.

Fragments of rock are the foreign bodies which are the most perplexing. The earliest recorded observation seems to be that by Phillips in 1865, followed by that of Noeggerath in 1862, both of which have been cited by Stur. Roemer<sup>79</sup> soon afterward described 3 small fragments from a coal bed in Upper Silesia; they were of crystalline rock, unlike anything known in Silesia. E. B. Andrews in 1870 announced the discovery of a waterworn quartzite fragment in the coal at Zaleski, Ohio, half embedded in the coal. Newberry in 1874 saw a fragment of talcose slate in the parting of Coal No. 1 at Mineral Ridge, Ohio, which he thought might have come from the Canadian Highlands; somewhat later he found a rounded quartzite fragment in the Block coal, resembling a Huronian rock in Canada. Stevenson in 1877 reported the discovery of a waterworn limestone boulder embedded in the Sewickley coal of Fayette county, Pennsylvania. It was about 2 feet in diameter and extended above as well as below the coal. He believed that it had not been deposited prior to the coal, for that was splashed as though the fragment had fallen into soft material. Similar notices appeared from time to time but in all cases they were merely casual.

Stur<sup>80</sup> in 1885 gave a summary statement of knowledge respecting such occurrences. He notes the discovery by Roemer in 1883 of a mass weighing 55 kilogrammes, granite such as is unknown in the region. He adds instances coming under his own observation in several Austrian coal fields, but the notes refer to somewhat widely separated localities and the fragments are of small size. Radcliffe<sup>81</sup> described 6 boulders from Dukenfield, England, embedded partly in the coal and partly in the overlying shale. The portion within the coal had a coaly crust but no such crust appears on the part within the shale. All are of quartzite and the weight was 5 to 166 pounds. One specimen was on edge. W. B. Dawkins

<sup>79</sup>F. Roemer, "Ueber das Vorkommen von Gneiss- und Granulit-Geschieben in einem Steinkohlenflotze Oberschlesiens," *Zeitsch. Deutsch. Geol. Gesell.*, Band XVI., 1864, pp. 615-617.

<sup>80</sup>D. Stur, "Ueber die in Flötzen reiner Steinkohle enthaltenen Stein-Rundmassen," etc., pp. 613-647.

<sup>81</sup>J. Radcliffe, "On Grooves and Quartzite Boulders in the Roger Mine of Dukenfield," *Quart. Journ. Geol. Soc.*, Vol. XLIII., 1887, pp. 601, 603, 604.

remarked in the discussion that such fragments occur frequently in Lancashire and that all are of quartzite; Bonney made the broader statement that they are of common occurrence in coal. In the same volume, J. Spencer referred to a granite fragment, weighing 6 pounds, which had been found in the Ganister coal bed and he adds that the surrounding coal was undisturbed. He remarked that bowlders had been found at many localities, that they were always isolated and that they had come from a distance. Gresley in 1890 reported that a well-rounded quartzite boulder, 11 by 8 inches, had been taken from underclay at 1 foot below the Mammoth coal bed near Mr. Carmel, Pennsylvania.

Orton<sup>82</sup> says that prior to 1892 the Ohio bowlders had come from the Middle Kittanning coal bed at Zaleski. The first was discovered by Andrews in 1870, but many were discovered afterwards, there being at times scores in a single room. The largest weighs 400 pounds and is in the State museum at Columbus. A new horizon was made by finding a quartz boulder, weighing 10 pounds and 10 ounces, at Mineral Ridge. It was in undisturbed coal at 2 feet below the roof and it was covered with a closely adhering, slickensided crust of coal. Stainier<sup>83</sup> gathered observations made by himself and others in the Belgian fields. Some of the fragments are rounded and smooth, evidently rolled pebbles, while others are irregular in form like concretions, but composed of sedimentary material and so are to be regarded as foreign bodies. Pebbles of the former type were obtained at 8 localities. They are not rare in La Rochelle colliery of Charleroi at the 500-meter level but they are wanting at the 250-meter level. The bed yields an impure coal and earthy partings are numerous where the pebbles occur. The largest is oval, 14 by 8 by 8 centimeters. Schmitz obtained rounded fragments from localities in the Charleroi and Centre basins, and Lohest found them in the Liège basin. The largest specimens weigh 20 and 25 kilogrammes. It is noteworthy that the Belgian fragments are

<sup>82</sup> E. Orton, "On the Occurrence of a Quartz Boulder in the Sharon Coal of Northeastern Ohio," *Amer. Journ. Sci.*, III., Vol. XLIV., 1892, p. 62.

<sup>83</sup> X. Stainier, "On the Pebbles Found in Belgian Coal Seams," *Trans. Manchester Geol. Soc.*, Vol. XXIV., 1896, pp. 1-19.

of sedimentary origin; some resemble Carboniferous rocks and all are in coaly material. These records seem to suggest that pebbles are not abundant in coal and that they are even of comparatively rare occurrence—the instances noted by Orton and Stainier are not exceptions, as they are examples of extreme localization.

Barrois<sup>84</sup> undertook systematic study of the matter in a definite area and presented the results in an elaborate memoir, of which only the merest synopsis can be given here. Most of the fragments were obtained during a four months' exploration of the Vein-du-Nord, a double bed, showing great constancy in the explored area, which is 7 kilometers long. The upper bench, 0.25 meter thick, has 14 per cent. of volatile and only 2 per cent. of ash, while the lower bench, 0.35 meter thick, has 17.2 per cent. of volatile and 10 per cent. of ash. The rock fragments are coated with soft sooty coal, often pyritous, and the lamination is more or less distorted about them. In all, 295 specimens were secured, of which 86 per cent. were derived from Coal Measures rocks, a few from Cambro-Silurian deposits and nearly 11 per cent. from the distant Archæan. The largest fragment weighs about 120 kilogrammes or approximately 280 pounds. The great preponderance of fragments from the Coal Measures shows that outcrops of those rocks were not far away, so that at the time of the Assise d'Andenne—the Lower Coal Measures—the beds of that epoch were no longer mere muds and sands, but consolidated shales and sandstones; some fragments show even the jointing of contraction. Many are thoroughly water-worn, others are angular, and both types are mingled indiscriminately. In some other coal beds of this region, fragments have been found in the mur, coated with clay which is marked with lacework of *Stigmæria* rootlets.

Fragments were found in all portions of the bed, from bottom to top, but the upper bench yielded 50 times as many as the lower. The number averages only one to each 100 square meters of area, but the distribution is irregular and they occur, as it were, in nests. The more abundant occurrences are associated with contractions of

<sup>84</sup> C. Barrois, "Étude de galets trouvés dans le charbon d'Aniche, Nord," *Ann. Soc. Géol. du Nord*, Vol. XXXVI., 1907, pp. 248-330.

the bed, where the roof or the underclay replaces more or less of the coal. Rolls in the roof usually consist of material differing in character and arrangement from the overlying shale, as though deposited in channels of streamlets made after formation of the coal. The underclay swellings may have been laid down in drowned channels made anterior to formation of the coal and occupied after that formation had been begun. Variation in direction of channels during accumulation of the beds might account for distribution of the fragments but the existence of such waterways within this area is problematical and it is well to seek another explanation.

Phillips's hypothesis that the fragments were transported by trees, uprooted from banks of streams, has found favor with allochthonists and autochthonists alike; but there are serious objections to it. The weight of some fragments, upwards of 100 kilogrammes, is too great to admit of transportation by *Stigmara*, while the presence of blocks of mud would suggest that hollow trees had shared in the work. In any event, there would always remain the remarkable purity of the coal, so difficult to explain in view of the great amount of inorganic material known to be transported by floating trees. There seem to be insuperable difficulties in the way of a conception that the presence of fragments is due to the agency of trees growing outside of the area in which coal was forming. Objection to the hypothesis of transport by floating ice is equally serious. Beyond doubt there were widespread changes in climatic conditions toward the close of the Palæozoic, but attempts to reconcile the tropical character of the Nord-basin flora with a cold climate have not been successful. The markings on the fragments do not resemble those made by glacial action.

The presence of fragments in the mur is proof that they were brought in prior to formation of the coal, when streams were distributing the detritus which became the mur. *Stigmara* became rooted in that and enlaced the fragments, which some day they were to transfer to the coal. The fall of trees, overturned in the marsh by age or wind, tore portions of the mur from below; fragments, there encased, came gradually to the surface of the coal; at times a stump fell into a stream and its load would be deposited in the

channel. This hypothesis explains local abundance of fragments by two factors; their previous existence in the mur and the fragility of the mur itself; so that they would form in succession part of the mur and part of the coal. The purity of the coal eliminates, during formation of the bed, the agency of convoys of allochthonous trees loaded with extraneous debris.

The condition is not peculiar to the Coal Measures. It is found in coal formations of other ages. Hutton<sup>85</sup> found in the Upper Cretaceous of southern New Zealand a sandstone mass, 8 feet by 3, resting on the coal, which convinced him "that there can be no doubt that this boulder has been floated to its present position among the roots of a tree and that therefore the coal beds are formed partly from driftwood." He states the Tertiary brown coals in several fields contain pebbles of white quartz; these beds, according to Hector, rest on fireclay. Jack<sup>86</sup> found pebbles in coals of Upper Cretaceous age in Queensland.

The presence of rock fragments in coal has always been perplexing to allochthonists and autochthonists alike, though each seems to be certain that in some way or another they afford an important argument in favor of his doctrine. They are certainly transported materials; some were brought from rocks far away and most of them are distinctly waterworn. If all were small, any geologist could conceive of an explanation, which would be satisfactory to himself, as refutation might be difficult; but when one has to deal with masses of several hundred pounds, such as the Ohio blocks, transported several hundreds of miles, the problem becomes serious.

Some writers have been inclined to regard ice as the transporting agent; but the character of the Coal Measures vegetation appears to be conclusive against the supposition that intense cold prevailed during any part of the year at any locality whence the fragments have been reported. It is very true that sharply contrasted climates may exist only a few miles apart, as in southern California, but that

<sup>85</sup> F. Hutton, "Report on Geology and Gold Fields of Otago," Dunedin, 1875, pp. 101, 103.

<sup>86</sup> R. L. Jack, "Geology and Palæontology of Queensland and New Guinea," London, 1892, pp. 536, 538.

condition requires topographical features which did not exist. The whole Coal Measures area of Ohio was a low plain; the nearest highlands were in Canada, hundreds of miles toward the north, and the Appalachians, hundreds of miles away toward the east. The agency of ice must be set aside as in the highest degree improbable.

The majority of authors have supposed that uprooted trees floated away carrying the masses entangled in their roots; but the difficulties involved in this conception appear to be insuperable. There can be no doubt that trees do seize such blocks and that under proper conditions they could transport them. Any one, who has seen the manner in which the white birch of the White Mountains enwraps its roots about blocks of stone weighing half a ton or more, recognizes that trees do seize large fragments. But that is not the question. The observer is confronted at once with the problem of conveying that tree and its load to deep water, sea or lake, where the great tree, 75 or more feet high, may float in vertical position, almost wholly submerged. Trees grow on the land, where alone the fragments can be obtained. The transfer cannot be made by torrents, as tree and load would be deposited at the first rapids. A débâcle, like that of Martigny or Johnstown, cannot be conceived of as the agent, since a topography would be required such as did not exist near any of the extensive coal fields whence large fragments have been reported. Even had it existed, the terrific collisions, as the flood dashed through narrow gorges and spread out in wider portions of the valley, would have dislodged the fragments long before reaching the open water. The bowlders cannot be relics of floating islands, such as those of the Orinoco, Amazon or Congo, since the origin of those islands forbids the suggestion.<sup>87</sup> Nor is there any reason to suppose that trees growing on the seashore could become the transporting agents, for, even though river-worn or wave-worn fragments were abundant on the shore, the difficulty of transferring the tree to deep water would still remain. If the trees grew on the river banks, along the lower reaches of a great stream, and were undercut, they would be stranded at the first bar to become

<sup>87</sup> "Formation of Coal Beds," these PROCEEDINGS, Vol. L., 1911, pp. 551, 553, 554.

snags or towheads, which even the greatest flood possible on such a river could not dislodge, as conditions along the Mississippi abundantly show. It is impossible to conceive of any means whereby a tree capable of carrying such a load could be floated away to deep water, unless it grew on the wall of a fiord—where it could not secure the water-worn fragments.

The assumption that shales, sandstones and conglomerates were deposited necessarily in deep water or in a permanent body of water must be regarded as unsupported by any positive evidence. The writer, during a tedious search through the literature, has not found that authors think that the proposition needs evidence; it seems to be accepted as axiomatic. But evidence to refute the doctrine abounds in the Tertiary and Quaternary and, in so far as the Appalachian Coal Measures are concerned, the facts seem to indicate that they are flood-plain deposits and reworked alluvial fans. This condition may afford a clue to explanation for some of the occurrences. Rivers, torrential in their upper reaches, flowed across the plain. Rolled fragments of varying size were pushed along the beds. Pebbles of quartz,<sup>88</sup> 5 inches in diameter, have been found in the Sharon of southern Ohio at not less than 300 miles from their source. During a great flood, if the stream were dammed temporarily, the water would sweep over the "bottoms" or break across the necks of curves; a new channel would be cut, the old channel above for a short distance would be scoured and its sand and pebbles would be strewn on the river-plain. This happens only too often along the Mississippi, as has been shown on preceding pages. In such a rush of water, a block of 400 pounds would be gathered up in the mass as readily as though it were a pebble; but gravity would act promptly and the coarse fragments in the load would be left scattered on the surface while the finer materials would go far beyond. Succeeding floods would cover the sands and gravels as well as the larger fragments with finer materials in which the larger river-worn masses would be widely separated, for the most part, though here and there they would be grouped in smaller areas. One finds this

<sup>88</sup> E. B. Andrews, Ann. Rep. Geol. Surv. Ohio, 1870, p. 67.

condition in the "bottoms" of large and small streams alike. The fragments in the underclay, mentioned by Barrois, Ashley and Gresley, were not deposited with the clay but before it; their distribution is wholly similar to what is seen now. The mode of transference to the coal, as described by Barrois, is in accord with what one may see in actual bogs; once transferred by plants rooted in the underclay, they would be removed successively into higher portions by plants rooted in the bog—for there is every reason to believe that the Coal Measures plants had as much liking for peat soil as is shown by many towering plants of the present day.

At the same time, the writer recognizes that the suggested explanation is not altogether satisfactory at some localities, where the required conditions cannot be proved.

#### MICROSCOPIC FEATURES OF COAL.

The unaided eye can discern many features of coal in the bed; it can group types into glance, matt, cannel, fusain; at times, it can find relations between a certain type of coal and the plants which produced it, so gaining insight into possibly contrasted origin of glance and matt coals; it can recognize great difference of physical features in the several benches of a coal bed, which lead to conviction that each bench may have had its own peculiar history, may have been formed under its own peculiar conditions, very different from those of the other benches. But one quickly discovers that intimate structure of coal can be ascertained only by aid of the microscope, since to the unaided eye, the great mass of coal is wholly structureless.

Nicol and Witham appear to be the first to apply this method of investigation, which Witham utilized especially in studying the structure of fossil plants. Hutton was the first who made a study of the coal itself. In a slice of coal, prepared by Witham, Hutton<sup>89</sup> observed some remarkable cells within the portions which showed no vegetable structure. He made sections of the coals mined at New-

<sup>89</sup> W. Hutton, "Observations on Coal," *Proc. Geol. Soc. London*, Vol. I., 1834, pp. 415-417; also in *Lond. and Edinb. Phil. Mag.*, Vol. II., 1833, pp. 302-304.

castle. These are, 1, Rich caking coal, which is the most abundant and the best in quality; 2, Cannel or Parrott or Splint; 3, Slate coal, consisting of the others in alternating layers so as to give a slaty structure. Vegetable structures can be recognized in all; but besides this, all show cells filled with wine-colored material, so volatile that it can be expelled by heat before any change takes place in the other constituents. The caking coal contains very few and those are elongated; he supposed that originally they were circular and that the changed form was due to pressure. The finest portions of the coal, in which "crystalline" structure is best developed, show no cells; the crystalline structure indicates a more nearly perfect union of the constituents, a more nearly complete destruction of the original plant texture. The Slate coal contains two kinds of cells, both filled with bituminous material; one kind is that seen in the caking coal, but the other is in groups of smaller cells, elongate circular in form. The first type occurs rarely in cannels and related coals, where the whole surface of the section is covered with an almost uniform series of cells of the second type, filled with the bituminous matter and separated by thin fibrous divisions. He was led by these features to believe that difference in coals is due to difference in the original plants. Another type of cells, empty, seem to have contained gas. It is clear that Hutton recognized a structureless portion of the coal containing plant fragments, of which the texture is still recognizable. He made no effort to explain the origin of the bituminous material.

Link<sup>90</sup> found vegetable structures in all coals and recognized that coal is made up of woody matter, usually much comminuted; but in some the structure is loose like that of modern peats, while others are dense like some denser peats of modern origin. Bailey in 1846 and Goeppert in 1848 described vegetable structures in coal. Dawson's<sup>91</sup> first important publication bearing upon the subject was in 1846 but his studies were continued for many years thereafter.

<sup>90</sup> H. Link, "Ueber den Ursprung der Steinkohlen und Braunkohlen nach mikroskopischen Untersuchungen," *Abh. k. Akad. Wiss.*, 1838, pp. 33-44.

<sup>91</sup> J. W. Dawson, "Notices of some Fossils found in the Coal Formation of Nova Scotia," *Quart. Journ. Geol. Soc.*, Vol. III, 1846, pp. 132-136; "Acadian Geology," 2d ed., 1878, pp. 393.

He rejected the use of prepared sections and resorted to the chemical treatment employed by Goeppert. The coal was broken up and the vegetable tissues were separated so as to exhibit their characteristics. He selected for study only specimens which in each case consisted of a single plant, so that he was enabled not only to ascertain the structural features of many forms but also to determine in great measure the share which each type of tissue had in making the coal. Reinsch, in 1881, utilizing prepared sections, elaborated Hutton's work and discovered great numbers of what he took to be very humble forms of vegetation.

Grand'Eury<sup>92</sup> laid emphasis on the vast proportion of amorphous material, the vegetable jelly, which holds the still recognizable plant remains. Clearly, much of the vegetable material was transformed into a kind of pulp, which forms a large part of the coal. "The great number of organs preserved in the form of teguments gives an idea of the quantity of vegetable jelly, which one finds to have formed the coal, in proportion to the epidermis material which is contained there." This jelly was not always so fluid or so homogeneous as to destroy all traces of vegetation for those are still recognizable. In the following year, von Gümbel<sup>93</sup> published the results of his elaborate studies of the fossil fuels from peat to anthracite. Throughout the whole series he recognized the amorphous material, Carbohum, clearly the vegetable jelly of Grand'Eury, the pulp of H. D. Rogers. He employed chemical processes to disintegrate the coals and to lay bare the vegetable structures, remaining in the enclosed fragments. He was enabled to show that while the glance coal consists of different kinds of vegetable matters, the predominating substance is the parenchymatous cells of the rind, along with tissue like wood, parts of leaves, epidermis flakes, separated disks and spore-like bodies, the whole enclosed in amorphous material. It is probable that the plant remains have been converted so thoroughly into homogeneous coal that determination of any vegetable

<sup>92</sup> C. Grand'Eury, "Memoire sur la transformation de la houille," *Ann. des Mines*, VIII., Vol. I., 1882, p. 109.

<sup>93</sup> C. W. von Gümbel, "Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen," 1883.

structure is very difficult. The matt coal consists mostly of prosenchymatous cells, which von Gümbel thinks derived from parts of leaves; much epidermis material is present along with spore-like bodies and broken fibrous coal. His conclusions in respect to these matters are like those reached by Dawson. Von Gümbel proved definitively the intimate resemblance of cannel, boghead and other forms to each other and to the Lebertorf of East Prussia. He recognized algæ-like forms along with spores in bogheads and cannels, thus anticipating much which has been published in later years. His figures illustrate well the characteristic forms, but evidently he had doubts respecting the relations, as he refrained from applying names to the forms.

Morris, Wethered and others early recognized spores in coal and some were inclined to attribute to these a very important share in the accumulation of coal beds. They seem to be in all coals. Nathorst<sup>94</sup> found macrospores very abundant in the great coal of the Devonian on Bear Island, south from Spitzbergen. Wethered and some others were regarded by Newberry and by Dawson as placing too much stress on the contributions by spores; while recognizing that spores are almost always present, and at times even in large numbers, they thought that these hardly deserve consideration as important constituents of coal. Kidston<sup>95</sup> has presented the matter in a simple way, which seems to meet requirements. He says that the quantity of spores from the lycopods was unquestionably enormous, and that they entered largely into the formation of some coals. There are bands composed wholly of megaspores and of microspores, varying in thickness from a mere membrane to a centimeter or more. In coal broken transversely, they give a zoned appearance, the bands of spores being distinguished by their dull color within the brilliant coal.

Van Tieghem,<sup>96</sup> in studying sections of flint concretions prepared

<sup>94</sup> A. G. Nathorst, "Zur der devonischen Flora der Bären Insel," *Handl. K. Svens. Vet. Akad.*, B. 36, No. 3, 1902, pp. 40-43.

<sup>95</sup> R. Kidston, "Les végétaux houillers recueillis dans le Hainaut belge," *Mem. Mus. Roy. d'Hist. Nat. de Belgique*, Tome IV., 1911, p. 208.

<sup>96</sup> Ph. van Tieghem, "Sur le ferment butyrique (*Bacillus amylobacter*) a l'époque de la houille," *C. R.*, Vol. 89, 1879, p. 1102.

by Renault, made the capital discovery that bacilli existed in Coal Measures time. Renault elaborated this observation afterwards in some memoirs which are captivating in style. The studies of bog-heads and related types by C. E. Bertrand and Renault fully confirmed the results presented by von Gümbel, while more recently new confirmation has come through the investigations by Potonié.

For the most part conclusions reached after microscopic study of coal concern chiefly the question as to the origin of the coal; some of them will find place on a later page. It is well, however, to consider the origin of the mineral charcoal or fusain, as that material has been deemed important in some of the hypotheses which will demand attention. It is present throughout the series of fossil fuels, even in peats, sometimes scattered in fragments, minute or considerable, scattered through the mass, at others forming distinct layers more or less persistent and up to 2 or 3 inches thick. Two partings in the Pittsburgh coal bed, continuous in an area of not less than 2,000 square miles, consist in most of that area of mineral charcoal mingled with impalpable mineral matter. The term mineral charcoal well describes the material; the vegetable structure is distinct, the substance is soft and soils the fingers.

Rogers<sup>97</sup> thought that leaves and fronds were brought to the marsh by winds or tides and that such parts as were not reduced quickly to condition of pulp, might remain as mineral charcoal, if the volatile constituents were removed rapidly. Three years later, Daubrée<sup>98</sup> studied fibrous coal from Saarbruck near Altenkirchen. Some specimens are pure black, with the fibers very fine, and resemble charcoal but are more tender; the fragments are irregular, angular and show little rounding of the edges. There is no transition between this and the surrounding coal and, according to Schimper, the fibers suggest those of coniferous wood. At the same locality is a dense type, less black, less brittle but very like charcoal; it contains 48 per cent. of ash. The material bears no resemblance

<sup>97</sup> H. D. Rogers, "Origin of Appalachian Coal Strata," etc., p. 462.

<sup>98</sup> A. Daubrée, "Examen de charbons produits par voie ignée à l'époque houillère et à l'époque liasique," *Bull. Soc. Géol. de France*, II., Vol. III., 1846, pp. 153-157.

to coke, to coal changed by dikes of igneous rock. He is certain that this fibrous coal could not have come from spontaneous decomposition of fibrous twigs, for in that case it would be like the enclosing coal. It is remarkably like the ordinary wood charcoal made by fire and it differs from coal as well as from anthracite by the structure and the volatile content. The ash varies from a trace to 70 per cent. He thinks that this fibrous coal is evidence of fires and refers to a great conflagration in 1844 near Saint-Leon in Landes, which was caused by lightning and destroyed 100 hectares of forest. In the discussion, A. Pomel dissented from Daubrée's conclusions because the quantity of this anthracitic fibrous material is too great to be the result of forest fires.

Dawson in 1878 summed up his conclusions which had been published in various forms in the interval from 1846. There is no possibility of accounting for a substance, so intimately mixed with the coal, by the supposition of conflagrations or of subterranean heat. The only satisfactory explanation is that afforded by the chemical changes experienced by woody matter, decaying in the presence of air, as described by Liebig. Mineral charcoal results from subaerial decay, the compact coal from subaqueous putrefaction, more or less modified by heat and exposure to air.

Grand'Eury<sup>99</sup> found fusain present in great quantity scattered in small patches throughout the coal. Stems of *Medullosa* and *Dadoxylon* are often carbonized and whole trunks of *Calamodendron* have been found converted into fusain enclosed in a crust of coal. Fusain is like charcoal; but some of it was exposed to moisture and dryness alternately. The subdivision of the material suggests the breaking up of wood in dry air; he thinks it indicates an extreme climate, for one does not find fusain in recent lignite or in swamps of today, but he has seen it in the older lignites. In any case it came at first from disintegration in air; other causes cooperated, but maceration does not give fusain.

Von Gümbel's conclusions are similar; the mode of occurrence, its peculiar disintegration and its loose structure show that it was in completely converted condition when taken up by the coal. He is

<sup>99</sup> C. Grand'Eury, "Memoire sur la formation," etc., pp. 106, 113-115.

inclined to believe that it was formed in free air, exposed to heat and moisture. Fayol<sup>100</sup> found fusain very abundant in the Grand Couche of Commentry. It occurs in isolated or grouped fragments between bright and dull laminæ, sometimes in heaps several meters long and 10 to 20 centimeters thick; he found it in the axes of brilliant laminæ of branches, especially of *Cordaites*, and in very numerous small fragments in the cannel. Fayol presents many facts which lead him to believe that fusain was formed by decomposition of plants in the air.

This material has been regarded by many writers as anthracitic. Perhaps it may have been so before burial, but the supposition that it could not be impregnated with substances coming from decomposition of the surrounding vegetable material seems to be disproved by McCreath's<sup>101</sup> analyses. At the same time it contains usually less volatile matter than is found in the enclosing coal, showing apparently that its origin was different. The analyses show a volatile content of from 6.40 to 30.74 per cent. The highest proportion is in specimens from a coal bed underlying the Homewood sandstone, in which the volatile is 48.140; a specimen with 11.36 is from a coal with 26.500; but there is one result, the average of several analyses, which gives 20.98, while the surrounding coal has only 17.070; the lowest, 6.40, is from a coal containing 21.410; while in one anthracite coal, the fusain contained 8.60 while the coal itself had 8.830. It is sufficiently evident that the volatile of the mineral charcoal bears relation in quantity to that of the enclosing coal.

The suggestion that mineral charcoal was derived from forest fires cannot be accepted as a possibility. The quantity produced by a forest fire is comparatively insignificant. The writer is sufficiently familiar with the subject to form a judgment. The Indians were accustomed to set fire to forests in many portions of the Rocky Mountains in order to drive the game to lower levels. The fires destroyed the bark and leaves but left the trunks little more than scarred. These remained upright until, weakened by decay, they were overturned by the wind to form the "laced timber," which was

<sup>100</sup> H. Fayol, "Études," etc., pp. 149, 177.

<sup>101</sup> A. S. McCreath, Sec. Geol. Surv. Penn., Rep. MM, 1879, pp. 106, 107.

always a terrible obstacle for exploring parties. Equally in the White Mountains of New England and in many portions of the Appalachians, the writer has seen forests of bare stems projecting above the young growth in areas which had been devastated by fires. The coals of Iowa and Missouri, in some beds, contain so much mineral charcoal that one would have to imagine a continuous conflagration for the whole area during accumulation of the coal.

#### VARIATIONS IN CHEMICAL COMPOSITION.

The independent history of the several benches of a coal bed is shown not only by the physical contrasts but also by the contrasts in chemical composition, which often are very great. Study of these makes evident that the period of time represented in some localities by a half-inch parting of mineral charcoal and impalpable clay may have been so long as to bring about serious changes in the surrounding conditions. Here one is concerned only with contrasts which seem to be original and not with those which may be due to influence of agencies belonging to later times.

The Bernice coal basin in Sullivan county of Pennsylvania is almost 40 miles from the anthracite area and the dips are extremely gentle. The area is insignificant, 600 yards wide and 2,400 yards long; yet it affords illustrations of differing composition which show the influence of very local conditions. The basin was described by Platt and the analyses were made by McCreath.<sup>102</sup> Platt's section shows two coal beds separated by 65 feet. The lower, 2 feet thick, has

Water .....	4.130
Volatile matter .....	15.270
Fixed carbon .....	67.362
Sulphur .....	0.523
Ash .....	12.715

with a fuel ratio of 1:4.41. Another analysis from a different part of the mine has very slightly less volatile but 3 per cent. more of

<sup>102</sup>A. S. McCreath, Sec. Geol. Surv. Penn., Rep. *MM*, 1879, pp. 82, 94, 97; F. Platt, *ibid.*, Rep. *GG*, pp. 176, 189-193.

ash. This coal does not coke and the rather voluminous gas burns with a feebly luminous flame. After drying at 225° F., the coal absorbs water rapidly, regaining within 2 hours about 60 per cent. of the quantity originally present.

The higher bed, known locally as Coal *B*, gives as the average of the three benches a fuel ratio of 1:10.289, an anthracite according to the ratio but an ordinary bituminous coal in appearance. The three benches show no notable difference in composition and the gases burn with feebly luminous flame. One mile away, a coal bed was seen, whose relations to the others could not be determined. At one opening it has 14.085 of volatile and 16 per cent. of ash, the fuel ratio being 1:4.57, and the gas burns with a non-luminous flame. At another opening the structure is, coal, 1 foot 3 inches, slate and fireclay, 6 feet, coal, 3 feet 8 inches; McCreath analyses show for the benches

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Upper bench.....	7.930	21.410	54.099	0.551	16.010
Lower bench .....	2.910	11.780	81.672	0.598	3.040

Ignoring the water and ash, the results are,

Upper bench .....	28.354	71.646	1:2.57
Lower bench .....	12.606	87.394	1:6.93

These Bernice coals, belonging in the lower part of the Pennsylvanian, differ from those in other small areas within Sullivan county, which, with fuel ratio of about 1:6, yield gas burning with brilliant flame. All are approximately at the same horizon. McCreath's reports contain many illustrations of noteworthy variation in composition of the benches.

The Spitzbergen coal<sup>108</sup> of Jurassic age is in appearance a typical coal. The bed mined in 1904 on Advent Bay is double; the upper bench averages about 3 feet and shows the same features throughout; the lower bench is 1 foot thick. The coal from the upper is

<sup>108</sup> J. J. Stevenson, "The Jurassic Coal of Spitzbergen," *Ann. N. Y. Acad. Sci.*, Vol. XVI., 1905, pp. 85-89.

hard, grayish black and with a fracture more or less conchoidal; while that from the lower is black, lustrous and somewhat prismatic, with some mineral charcoal. These coals were analyzed by A. S. McCreath, who obtained as the average of several determinations for each

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Top.....	3.310	19.790	62.763	0.467	13.670 gray
Bottom .....	4.696	28.560	57.171	0.413	9.160 light brown

The fuel ratio for the top is 1:3.17 and that for the bottom is 1:2, there being a difference of somewhat more than 9 per cent. in the volatile matter.

Gruner says that the Grande Masse of the Rive-de-Gier formation is double, the benches being separated by the "nerf blanc," a white sand parting less than one third of an inch thick. The lower bench or "rafford" is hard and dull, suitable for use in grates, but the upper or "marechal" is tender, brilliant, less rich in oxygen and employed in making gas and coke. There is very great variation in the several parts of the Grande Couche at Decazeville but, according to Fayol, the Grande Couche at Commentry seems to approach homogeneity throughout.

Barrois,<sup>104</sup> interested by the work of Muck, Stainier, Strahan and others bearing upon this question, secured analyses of the coal from several beds near Aniche (Nord), the samples being taken for each decimeter from roof to floor. The ash varied in one bed from 2 to 8 per cent.; in another from 2.2 to almost 8; in a third, from 1.6 to 11.6 and in a fourth from 1 to 6.4—the faux-toit and faux-mur being neglected. The beds are thin, from 0.6 to 1 meter, and the samples were taken without reference to the partings. The results show definitively that conditions were not the same throughout the accumulation of even a single bench. The volatile in different parts of a maigre coal varied 6 per cent. and in a demigras coal, 8 per cent.

<sup>104</sup> C. Barrois, "Observations sur les variations de composition du charbon dans certaines mines d'Aniche," *Ann. Soc. Géol. du Nord*, Vol. LX., 1911, pp. 177-186.

Reports on composition of coal show similar variations in all coal fields.

Some coals cake when heated, others do not. The available methods of analysis lend no assistance toward explanation of the difference. Some have supposed it to be physical, that the glance or caking laminæ are separated so completely by the dull laminæ that fusion becomes impossible; but this can hardly be regarded as established, for in some portions of the Connellsville basin, the coal cannot be distinguished in hand specimens from the non-caking coal of Massillon, Ohio, yet it yields the standard coke. Nor does the proportion of mineral charcoal seem to be important, since the caking coal near Uniontown, Pennsylvania, has as much as some non-caking coals of Missouri. It has been suggested that the Cretaceous coals of Colorado and New Mexico are caking in some localities, non-caking in others, because of the nearness or distance of igneous rocks. Unquestionably, there is much to be said in favor of this suggestion, yet there is much room for the other suggestion that possibly coincidence may have been mistaken for cause and effect. It is not certain that the influence of dikes can be exerted very far through coal or the accompanying rocks. Several of the coal beds in southwestern Pennsylvania are of caking coal, while there are others in the immediate vicinity whose coals are non-caking. There is no reason to suppose that eruptive rocks have exerted influence there. Incomplete conversion of the material as shown by the action of caustic potash is supposed by some to account for non-caking property, there are coals of Cretaceous age, which are attacked energetically by caustic potash, yet make a firm coke. The suggestion has been made that possibly the presence or absence of sapropelic material may determine the extent of caking. This is possible.

The analyses by Carnot<sup>105</sup> led him to interesting conclusions. He procured 18 samples of coal from Commentry, representing several genera of plants. Ultimate analysis showed that the elementary composition of these coals is almost accurately the same throughout,

<sup>105</sup> Ad. Carnot, "Sur la composition et les qualités de la houille, en regard à la nature des plantes qui l'ont formée," *C. R.*, Vol. 99, 1884, pp. 253-255.

but proximate analysis showed great differences in volatile constituents, due to difference in combination of the elements. Ignoring the ash, he found the volatile and the coke as follows:

<i>Calamodendron</i> .....	35.3	Well agglomerated.
<i>Cordaite</i> .....	42.2	Rather swollen.
<i>Lepidodendron</i> .....	34.7	Well agglomerated.
<i>Psaronius</i> .....	39.5	A little swollen.
<i>Ptychopteris</i> .....	39.4	A little swollen.
<i>Megaphyton</i> .....	35.5	Well agglomerated.

He found similar contrasts in modern woods, almost identical in composition, and his conclusion is that plants preserved in coal appear to have different properties though having the same elementary composition, and that external influences were not the only ones affecting the composition and character of the coal. A casual examination of the table might lead one to suppose that the proportion of volatile matter had its influence on the tendency to cake, since the well-fused coke was given by coals with about 35 per cent.; but this may be only a coincidence. Washed "slack" from the Pittsburgh coal at Laramie, Pennsylvania, contains, without ignoring the ash, as high volatile as even the *Cordaite*s coal of Commentry; it was tested extensively more than a third of a century ago, its coke was strong and with it some extraordinary runs were made in a furnace, 100 feet high. All that one can say is that caking may be due to the presence of special hydrocarbons—a sufficiently safe and at the same time a sufficiently broad suggestion.

#### THE INORGANIC CONTENT OF COAL.

The ash or incombustible portion of coal varies in quantity and composition not only in different beds but even in the same bed, horizontally as well as vertically. It may be fine, powdery, a constituent of the coal itself, or it may be coarse, cindery, coming in great measure from slates or partings. Glance coal is often almost free from ash but the matt coal always has more while the cannels very often have a high proportion.

In making an effort to compare coals, one is dependent neces-

sarily on such analyses as can be reached ; but here, at the very outset of the inquiry, the worth of these analyses is a matter of doubt. Formerly, samples were selected at random, fragments taken from a heap were supposed to represent the average of the bed. For many years, however, sampling in the United States has been on the commercial basis and very frequently the effort has been to ascertain the run of mine composition. Analyses of samples collected according to the different methods are, evidently, not of equal worth for comparison, though it must be conceded that in a very great proportion of cases, results obtained by the old method are remarkably like those obtained by the new.

Allied to this is the other query as to how much of the deposit is to be considered in determining the impurity of the coal. There are those who, in a discussion like this, would throw out of consideration all partings, thick or thin, and would consider only the coal itself, holding that partings, as interruptions in the process of formation, have only indirect bearing on the subject. But others maintain that no part of the bed should be neglected, as the deposit must be considered as a whole. There is some degree of propriety in each contention. Study of the coal itself gives a nearer approach to the nature of the vegetable material forming the coal, it may give approximately a conception of what may be termed the original inorganic material ; while study of the whole deposit may give a clue also to foreign matters introduced during formation. Yet one finds himself confronted at once by a question as to the significance of partings ; in one locality they may be mere films of fusain and impalpable clay separating benches of the bed, whereas in another, one or more of these partings may have swollen to a mass of shale or sandstone or both, many yards thick. Some coal beds, like the Waynesburg, have clay partings, 6 to 12 inches thick. Occasionally one of these persists after the underlying or overlying bench has disappeared. The question arises Should the sample be taken where the partings are thin or where they are thick ? Should the sample be taken where the bed is practically single and another where the bed is divided, the latter to include the intervening sandstone, shale and perhaps limestone ?

Comparison of analyses means not much unless one knows the method of choosing the samples; no definite conclusions respecting conditions under which coal was deposited can be based on a mass of analyses gathered indiscriminately from all quarters of the globe. It might be that the ash would tell much, if all portions of a bed were studied, each by itself; but even then the information might be too localized. Another difficulty is that published analyses, with a small proportion of exceptions, are of coal supposed to have commercial value, so that they do not give a proper conception of the character of the greater part of coal beds. Thus, Stainier<sup>106</sup> compared 2,568 analyses, gathered from reports on coal areas in Europe and America. Of these only 15 per cent. showed more than 10 per cent. and less than 2 per cent. had more than 20 per cent. of ash. It is very certain that the 2,250 analyses, giving less than 10 per cent., were not all made of prisms representing the whole bed; and equally that the coal was taken from localities which were promising from the commercial standpoint. This is beyond dispute, since more than one half of the analyses report 5 per cent. or less of ash. It is unsafe to take the average of such analyses as representing a probable average condition. Most of the coal horizons show extreme variations which at times are abrupt, so that, while a sample from one locality may have but 5 per cent., another, only a short distance away, may have 25 per cent. It is quite probable that if analyses were made of all the coal beds in some small areas of southwestern Pennsylvania, where the column is long, the results would show that more than half of the beds have more than 10 per cent. of ash. One must recognize that in many localities the conditions did not favor the accumulation of clean coal; in the higher portions of the Coal Measures, within the bituminous region, the beds are all poor, broken by thin slates, no analysis showing less than 12 per cent. and most of them above 16 up to almost 32.

The difference in ash-content of the benches of a coal bed may be very great. A. S. McCreath's analyses of several beds in Pennsylvania show, for those in the Allegheny, differences between the

<sup>106</sup> X. Stainier, "Notes sur la formation des couches de charbon," *Bull. Soc. Belge de Géol.*, Vol. XXV., 1911, P. V., pp. 73-91.

upper and lower benches of 16, 13, 14, 12, 11, 9, 8, 7, 5, 4, 3, and 2 per cent. Sometimes the upper, at others, the lower is the less clean. Often there is no difference in appearance but usually the cause of greater impurity is distinct, for the filmy partings of black shale are apparent. Local variations are equally well marked in analyses by the same chemist. The ash in the Lower Freeport varies from 1.80 to 10.53 per cent. and in the Middle Kittanning from 3.48 to 12 per cent., the samples in every case being of coal which is mined. It must be evident that a collection of analyses from all regions cannot be utilized for generalization. Conditions varied locally at each horizon, so that while worthless coal was accumulating in some places, good coal was accumulating in others; equally, the conditions varied greatly during the period of formation, so that one bench may be clean and another worthless.

But a promiscuous collection of analyses is not merely worthless as a basis for generalization, it is also very apt to be misleading by diverting one's attention from consideration of the features which are really important. One is not concerned with averages of coals all over the world or in the proportion of analyses showing more or less than 5 per cent. The really important matter is the composition of a particular deposit within a large area. When this has been ascertained, one finds that the difficult problem is not to account for the excess of ash but for the astonishing deficiency in ash, observed in some beds throughout very great areas. Analyses by A. S. McCreath and by Hite and Patton<sup>107</sup> show that the Campbell's Creek coal bed in 4 counties of southern West Virginia gave as the result of 26 commercial samples, 5.943 per cent. of ash and all were of outcrop coal, yet 10 of them had less than 5 per cent. In 4 other counties, the average of 34 commercial samples is 5.52 per cent. and several had less than 3. Commercial samples of the Pocahontas coal from 38 localities in southern West Virginia showed from 2.34 to 9.58 per cent., with an average of 4.63. The Pittsburgh usually has 7 per cent. or less. All of these are in areas of from 2,000 to 6,000 square miles or more. Evidently there are coal beds which in

<sup>107</sup> W. Va. Geol. Surv., Vol. II., 1903, pp. 695, 696; Vol. II. a, 1908, pp. 393, 394.

immense areas have not so much ash as one should expect; they have less than the original plants should have contributed. This is the important matter for consideration; there is no difficulty in accounting for high ash in coal, but there is great difficulty in accounting for coal which, in areas of thousands of square miles, have too little ash.

The ash in different beds as well as in different parts of the same bed may show notable differences in composition. The White Ash coal bed, of Upper Cretaceous age, near Cerillos in New Mexico, is of interest because in the mines one can follow the coal in its passage from high grade bituminous, thoroughly caking, with 39 per cent. of volatile, and 5.24 of ash, to a typical anthracite with 93 per cent. of fixed carbon and 5.78 of ash. This change takes place within little more than 2,000 feet and is due to influence of a sheet of andesitic rock. Church<sup>108</sup> analyzed the ash from both types, the samples being taken from car-load lots and representing the coal as shipped to market. His results are:

Silica .....	26.93	32.14
Alumina .....	32.41	36.58
Oxide of iron .....	3.96	12.86
Lime .....	24.68	8.19
Magnesia .....	10.32	5.11
Sulphate of calcium .....	0.21	0.18
Soda .....		1.36
Potash .....	1.49	3.59

McCreath<sup>109</sup> has given the composition of ash from 2 samples of Red Ash and 7 of White Ash anthracite which may be compared with that from the bituminous Upper Freeport at 3 localities in Jefferson and Clinton counties.

The bituminous coals contain 4.150, 3.100 and 9.125 per cent. of ash respectively. A series of 21 analyses given by Muck<sup>110</sup> show similar though greater variations. The silica is from 1.700 to 53.600; alumina from 2.210 to 41.110; sesquioxide of iron from

<sup>108</sup> W. D. Church, cited in J. J. Stevenson, "The Cerillos Coal Field," *Trans. N. Y. Acad. Sci.*, Vol. XVI., 1896, pp. 117, 118.

<sup>109</sup> A. S. McCreath, *Rep. M.*, p. 27; *Rep. MM.*, p. 375.

<sup>110</sup> F. Muck, "Die Chemie der Steinkohle," pp. 98, 99.

	Red Ash.	White Ash.	Jefferson.		Clinton.
Silica .....	47.190	48.250	44.82	39.25	47.585
Alumina .....	35.522	36.177	42.41	39.20	40.117
Oxide of iron.....	4.700	3.290	5.30	13.55	6.143
Lime.....	3.640	1.950	1.44	3.87	0.960
Magnesia.....	0.965	0.921	3.90	2.90	0.731
Sulphuric acid.....	0.712	0.490			0.392
Phosphoric acid.....	1.958	0.923		0.26	0.123
Titanic acid.....	0.990	0.750			1.190
Alkalies, loss.....	7.313	7.249	2.13	0.77	1.486

5.590 to 74.800; lime from 1.080 to 21.540; magnesia from 0 to 9.823; potash and soda from 0 to barely 1 per cent. McCreath reports a small quantity of alkalies in nearly all cases. Where the proportion of iron is large the coal is pyritous. Potash is present in all terrestrial plants, though not always as carbonate. Dieulafait<sup>111</sup> examined the ashes of 168 specimens of recent *Equiseta* collected at various localities in Europe and northern Africa. Alkaline carbonates were wanting but calcium sulphate and potassium sulphate are present in large proportion; yet plants of other types, growing in the same localities, gave ash of the ordinary kind, rich in carbonates and poor in sulphates.

The ash analyses to which reference has been made are for the most part from coals without notable commingling with slates. It is altogether probable that ash from commercial samples would show the same materials, though no doubt in slightly different proportions, as it would contain silts brought in and deposited on the forming coal. But in this connection, one must not forget that wind may contribute towards addition of foreign materials. The presence of atmospheric dust is an only too familiar phenomenon on sea as well as on land, but one is in danger of underestimating its importance. James Douglas has informed the writer that coke from Connells-ville, exposed in heaps to the winds of Arizona for a few weeks, showed almost 30 per cent. of ash, though it originally contained not more than 14. This change was in the arid region where dust is abundant, but it suffices to show the possibilities elsewhere.

<sup>111</sup> M. Dieulafait, "Composition des cendres des *Equisetacées*," *C. R.*, Vol. 100, 1885, pp. 284-286.

Taylor<sup>112</sup> compared the ash of good and bad coal with underclay, bituminous shale and blue shale. The constituents are alike in all though the relative proportions differ. The good coal with 1.36 of ash and the poor coal with 16.9 of ash compared with the underclay show

Silica.....	59.66	64.21	62.44
Alumina.....	12.19	28.78	31.22
Sesquioxide of iron.....	15.96	2.27	2.26
Lime.....	9.99	1.34	0.75
Magnesia.....	1.13	1.12	0.85
Potash.....	1.17	2.28	2.48

Bischof thinks that the analyses show close relationship throughout and that they indicate sedimentary origin for all the materials alike. He says that the variation in composition of the earthy matters in coal is not greater than in shales. McCreath has analyzed many of the Pennsylvania fireclays and the results show great variation, the silica from 47 to 66 and the alumina from 18 to 35 per cent. A similar variation is found in the Pleistocene clays. The resemblance between coal ash and the clays ought to be close in respect of constituents, it matters not whether the coal is allochthonous or autochthonous, but some of the differences offer abundant ground for speculation.

The large proportion of clay in coal ash is, for some, evidence that the material is of extraneous origin, since clay is an extremely unimportant constituent of plants. It is insignificant in the ash from peat. Mills and Rowan<sup>113</sup> give analyses from 27 Irish localities which show in the ash 0.129 to 10.705 of alumina, but 12 of them have less than 1 per cent. and only 3 have more than 3 per cent. It must be remembered, however, that the trees and the peat forming plants of the recent period are not the same with those which gave the coal. The most important plants during Coal Measures time were lycopods and equisetæ. Dana<sup>114</sup> cites analyses of some

<sup>112</sup> H. Taylor, cited by G. Bischof, "Elements of Chemical and Physical Geology," London, 1854, pp. 268, 269.

<sup>113</sup> E. J. Mills and F. J. Rowan, "Chemical Technology," *Amer. Ed.*, Vol. I., 1889, pp. 16-18.

<sup>114</sup> J. D. Dana, "Manual of Geology," 4th ed., 1895, pp. 74, 75, 663.

forms belonging to those types, which show for lycopodium ashes 22 to 57 per cent. of alumina and 10 to 14 per cent. of silica; for Equisetum, no alumina but 41 to 70 per cent. of silica. The ash of lycopods is 3.2 to 6 per cent. of the dried plant; of ferns, 2.75 to 7.56; of equisetia, 18.71 to 26.75. Stainier cites Wolff, Czapele and Violette; lycopods have 4.70 to 6.10 per cent. of ash; conifers contain very little ash in the wood but their bark and leaves have much more, the former from 1 to 2 and the latter, from 5 to 7 per cent. Coville<sup>115</sup> has given a table of analyses, showing the quantity of lime in leaves of trees, the percentage of the dried leaf varying from 1.73 in the red oak to 4.38 in the ginkgo, the modern representative of the *Cordaites*.

Lycopods compose the greater part of most coals, other plants giving the less part—though there are beds consisting very largely of *Cordaites*. Dana has calculated that if the original ash were 1.66 of aluminium silicate and if the plant material lost three-fifths of its mass during transformation into coal, there should remain 4.15 of silica and alumina, the total ash being 4.75 per cent. of the coal; and this without introduction of any inorganic matter from without by either wind or water, the whole being derived from the soil in which the plants grew. Coal is known to consist very largely of flattened stems, the cuticle alone remaining; the other parts of plants have been almost wholly decomposed into a structureless pulp, of which not a little may have been removed by solution. Bark and leaves make up a very great part of the coal. One should expect to find in ordinary coal not much less than 6 per cent. of ash, or even more, in which silica and alumina should predominate greatly.

Yet there is the all-important fact that some coal beds in areas of several thousands of square miles have not merely less but even very much less than the normal quantity of ash. The fact that many coal beds have more is unimportant; no one, be he allochthonist or autochthonist, finds any difficulty in explaining the excess of inorganic matter. But the Pittsburgh, Campbell's Creek, to make no reference to some other beds, have less and the condition in those

<sup>115</sup> F. V. Coville, "The Formation of Leafmold," *Journ. Wash. Acad. Sci.*, Vol. III., 1913, p. 80.

beds is not local; they are mined in all parts of their areas and yield scores of millions of tons each year; the analyses are of commercial samples so that they show more ash than the coal itself would show, apart from the thin partings of mud due to overflows. These coals have less inorganic matter than the plant substance should have yielded, which shows that, where accumulation proceeded in a normal way, the product is likely to contain diminished ash. In advancing change by metamorphosis or otherwise the ash is reduced, as appears from analyses of the New Mexico coal and of coals from the anthracite fields of Pennsylvania.

It is wholly probable that not a little of the original inorganic content was removed in solution. Maceration takes much from flax and Fayol ascertained that the same effect is produced on hemp. Wood floated down the Rhine loses much during the journey. Besides this, the organic acids form slightly soluble salts with several bases, which would be removed by leaching. Evidently some areas in southeastern Kentucky, where a coal bed shows less than 1 per cent. ash in commercial samples, must have been in an exceptionally favorable position, where the accumulating coal was protected from flooding by muddy water but exposed to leaching.

### THE ROOF.

The normal roof of a coal bed is shale, often resembling that of the mur in composition but differing in structure.. Roof shale is more or less laminated but ordinarily there is no trace of lamination in the underclay. In what may be termed normal conditions, the passage from coal to roof is gradual, there being a faux-toit, in which foreign matters increase gradually until at the top all traces of coal have disappeared. This may be a bone or a bony coal, with external appearance of cannel, or it may be a coarse worthless coal, made up of alternating layers of bright coal and black shale loaded with leaves or flattened stems. It may be only a few inches thick or it may continue, as in the Pittsburgh bed, through 3 to 16 feet of measures. Sometimes, the passage is abrupt, as seen at the partings or, so to say, the subordinate roofs of a coal bed, which, as has been

seen, often mark crises in accumulation of the mass. Not infrequently the sand and clay laminæ of the roof disappear and the coal is almost a solid layer, but evidence of unfavorable conditions still remains in the high ash.

At many localities the roof shale, composed of fine materials, contains a profusion of plant remains, stems, fronds, leaves, retaining the most delicate markings. Prostrate tree-trunks have been traced in some cases scores of feet and twigs, with the branchlets and leaves attached, have been found in considerable areas, the fossils often as perfect as though they had been preserved in a herbarium; the fronds of ferns at times show all parts in place and as little disturbed as though they had fallen at the foot of the parent plant. The whole arrangement indicates a gentle deposition of the silts as that during overflow of the bottom swamps by muddy water during rise of a Mississippi flood. But this is not always the condition. Renier<sup>118</sup> states that one rarely finds in the Belgian coal fields such remarkable specimens as are described as occurring in other countries. For the most part, the plant remains are fragmentary. So in the Appalachian basin; there are many localities where the remains are beautifully perfect and there are many others in which the remains, though retaining the delicate surface markings, are fragmentary and distinctly not in place. The silts were not deposited as gently in some places as in others. Occasionally vertical stumps are seen, with their roots spread out in normal position over many square yards and still preserving the fragile rootlets, which pass off in all directions as in a living plant. These erect trunks, standing amid prostrate stems and vegetable debris, such as one finds on the surface of forested swamps, rarely pass upward from the coal. It is true that there would be difficulty in tracing the tree downward in case the peat became structureless coal and that the opportunity to make the effort would be a rare one in a mine worked for commercial output, but occasionally the exposure occurs and a

<sup>118</sup> A. Renier, "Observations paléontologiques sur le mode de formation du terrains houillers belges," *Ann. Soc. Géol. de Belgique*, Vol. XXXII., 1904, Mem., p. 261 et seq.

geologist happens to be present at the time. Wilkinson<sup>117</sup> states that near Newcastle he saw several trunks of trees, up to 1 foot thick and with roots attached, starting from a coal seam and embedded in the strata in the original upright position. More commonly the trees found in the shales with attached roots *in situ*, though of the same general character as those making much of the coal, are not rooted in the coal itself but in the shale. In not a few cases, their relations suggest that they grew on spaces covered with detritus, such as one sees in the large forested swamps, where trees, belonging to species rooting indifferently in peat or in inorganic matter, are growing on sand or clay-covered spaces and with their roots extending beyond to the peat itself. Partings in coal beds unite in themselves the features of roof and floor; at times they contain abundance of plant remains and still serve as soil on which a new vegetation arises. Renier has given an illustration. The roof shale of a coal bed is about 4 feet thick. It contains 12 species of plants but, at a little way above the bottom, there appear in addition *Stigmaria*, which increase in number toward the top where one reaches another coal bed. In some cases the rootlets of *Stigmaria* have pierced the leaves of other plants, but in most cases they have avoided that exertion and have moved around them. Robb, Williamson and others have described *Stigmaria* rooted in parting clays and Williamson has told of a stem rooted in the parting and passing upward into the coal.

The roof shale varies in color from gray to black, is usually quite fine in grain and argillaceous, though often notably arenaceous. The features are as characteristic in later formations as in the Coal Measures. The dark color is due to organic matter, which is not always derived wholly from land plants, since the deposit at times is not of flood-plain origin. The roof of the Upper Freeport coal bed exhibits the contrast. In extensive areas, it is of the ordinary type, with reasonably well preserved plant remains, but, at some widely separated localities, it contains along with very fragmentary plant remains great abundance of marine fossils, belonging to types

<sup>117</sup> C. S. Wilkinson, "Mines and Minerals Statistics of New South Wales," Sydney, 1875, p. 130.

commonly regarded as requiring deep water. The Middle Kittanning in much of Ohio is easily recognized by means of its marine shale roof. Lesquereux has mentioned several instances in Kentucky and the Pennsylvania geologists have added many more. Absence of plant remains is reason for suspecting that the shale is not a terrestrial deposit, even though remains of animals appear to be wanting. Boulay<sup>118</sup> was puzzled in several instances by a roof apparently normal but without trace of plants. Very close examination revealed an exceedingly thin layer with *Mytilus* at 4 or 5 inches above the coal. In many cases within American coal areas, the prevailing forms in the roof are *Lingula* and *Orbiculoidea*, which are shallow water forms, but there are roof shales, usually somewhat sandy, containing *Productus*, *Spirifer* and other forms which belong to the so-called deep-water fauna. The condition is quite commonplace in modern times. Instances of peat deposits directly underlying marine clays and sands were given on preceding pages and many additional instances could be cited if necessary.

Limestone is by no means an uncommon roof; it is characteristic of several coal beds within the Beaver formation. I. C. White has recorded many instances in Pennsylvania; Orton, Jr. and A. A. Wright have done the same for Ohio and I. C. White reports the same condition at localities in southern West Virginia. At all of these localities the limestone is marine; but contact with the coal is not found throughout, for very frequently the coal and limestone, in contact at one locality, are separated by several feet of shale or even sandstone at others. The lowest coal bed of the Allegheny in Ohio often is in contact with the overlying marine limestone, and the Harlem coal bed of the Conemaugh is at times directly under the marine Ames limestone, though usually a considerable mass of shale intervenes. So in the Illinois field where Worthen<sup>119</sup> found his coals III. and VI. with a marine limestone roof. This is not unusual enough to be surprising; some instances have been reported

<sup>118</sup> l'Abbe Boulay, "Recherches de paléontologie végétale dans le terrain houiller du Nord de la France," *Ann. Soc. Scient. de Bruxelles*, 4me année, 1879, sep., pp. 33, 47, 57-59.

<sup>119</sup> A. H. Worthen, *Geol. Surv. Illinois*, Vol. III., 1868, pp. 12-13.

from Iowa and Indiana; Tschernychew and Loutougin<sup>120</sup> state that four coal beds in the Donetz basin of central Russia have marine limestone or calcareous shale as the roof material. Coals of the Monongahela and higher formations frequently have non-marine limestone as the roof material. Lipold has shown that the Triassic coals of his area sometimes have shale but at others limestone roof. Von Gümbel and de Serres have described beds of lignite with limestone roof. Peat deposits have in most cases either clay or sand roofs but calcareous roofs have been recorded on a preceding page.

Occasionally a coal bed is found between marine limestones. Fayol saw at Fontaine near Mariemont in Belgium two beds of anthracite, 3 meters apart, intercalated in marine calcareous shale. He thinks that, according to the *in situ* theory of origin, it would be necessary to suppose that the lower limestone, produced in deep water, was lifted and emerged; then that a submergence of similar amplitude occurred after formation of the first coal bed; that a second emergence succeeded the deposit of 3 meters of limestone and that a second submergence followed formation of the second anthracite bed. Be that conclusion good or not, it is certain that occasionally a coal bed is seen in contact with marine limestone above and below; Illinois Coal VI. not infrequently has this feature, though it must be said that in areas of hundreds of square miles it is separated by several feet of clay below and of shale above. The Tertiary coal at Häring, as well as some south Bavarian coals of the same age, is said by von Gümbel to be between limestones: he thinks that the former was a cedar swamp. Virlet d'Aoust<sup>121</sup> has described the section exposed in a great excavation east from Havre. He saw there 3 characteristic beds of peat, which are merely intercalations in a mass of very calcareous clay, containing abundance of marine shells belonging to *Cardium*, *Mytilus* and other genera.

It is quite possible also for accumulation of coal to be inter-

<sup>120</sup> Th. Tschernychew and L. Loutougin, "Le bassin du Donetz," Guide des Excur. VII<sup>me</sup> Cong. Géol., 1897, XVI., pp. 13, 14.

<sup>121</sup> Virlet d'Aoust, "Note sur le terrain d'atterrissements récents de l'embouchure de la Seine," *Bull. Soc. Géol. de France*, II., Vol. VI., 1849, pp. 606-625.

rupted by ingress of marine conditions. The Harlem coal bed at a locality in Ohio and at one in West Virginia has marine forms in the upper part; the condition is common enough in recent times; Belgrand found a peat on the Seine which has many shells and passes upward into a peaty clay and sand, full of shells; Yates described a submerged forest in Cardigan bay where the stems of *Pinus sylvestris* had been bored by *Pholas* and *Teredo*, after which the peat-making was resumed.

Barrois<sup>122</sup> classified the roofs which occur in a portion of the Nord basin. He found, (1) sandstone, an offshore deposit, with casts of trunks and branches of land plants; (2) shale with plants, carbonaceous, remains abundant and well preserved, by their size and distribution showing short transportation—they fell into the mud from plants or were blown by the wind; (3) carbonaceous shale, thin cannell-like, micaceous and pyritous, with remains of fish—the water was brackish, marine or fresh, little disturbed and deposition was slow; (4) bituminous shale, brown, contains pelecypods and crustaceans—thicker than 2 and accumulated more slowly in fresh or brackish water, is often rich in fragmentary plant remains and in fusain; (5) calcareous shale with marine shells, accumulated in deeper waters open to tides. Numbers 1 and 2, which he terms Group *A*, are to be regarded as deposited by disturbed water on a swampy surface, at times dry and never covered with water more than 5 meters deep. The others, forming Group *B*, were deposited in the deeper water of ponds, lakes, gulfs, as shown by the finer grain and the association of plant remains with those of animals.

Erect trees, parallel among themselves, occur frequently in the area examined. If these had been floated in from the land, they should be found almost exclusively in roofs of Group *B*, deposited in deep water; on the other hand, they should be rare in Group *A*, formed in shallow, muddy water, where they would be buried without being able to retain the erect posture. But the studies show that

<sup>122</sup> C. Barrois, "La repartition des arbres debout dans le terrain houiller de Lens et de Liévan," *Ann. Soc. Géol. du Nord*, Vol. XL., 1911, pp. 187-196.

there are no erect trees in the deep water roofs of Group *B*, where only broken plant fragments were seen; whereas they are found in the, at most, shallow-water roofs of Group *A*, where leaves occur, *in situ*, spread out flat and intact. In the collieries at Lens, 19 roofs with plant leaves *in situ* have erect stems: 7 of these roofs contain, elsewhere, fragmentary plant remains and lacustrine shells, but not one of these contain such remains in the localities where they have erect trees. All the erect trees were found in roofs of the Group *A* type; not one was found in any roof which is persistently of the *B* type; 28 such roofs exist in the Lens area and all were studied. At Liévan, 7 roofs of the *A* type have yielded erect stems, but none has been discovered in any of the 17 roofs belonging to the *B* type.

These detailed studies, made in small areas where the conditions are apparent, confirm the opinion of Dawson based upon study of the Acadian outcrops and fully justify the conclusion reached by Barrois; erect trees are not found in deposits laid down in water deep enough to permit floatation; they are found only in deposits on which there was never more than a shallow cover of water.

#### IRREGULARITIES IN THE ROOF.

In all coal beds there are what the miner calls "troubles." Some of these, such as "clay veins" for the most part, are due to disturbance after the column had been deposited, as they pass into overlying rocks; others, irregularities of the bottom, were due, ordinarily, to the uneven surface on which the coal accumulated; but there are many which mark the courses of streams which continued after accumulation of vegetable matter had begun and were obliterated slowly by encroaching plants.

Irregularities in the roof are generally much more perplexing than those in the floor. They are the "washouts," to which reference is made in almost every work on coal fields, and they are closely related to the greater "washouts" or filled valleys. In those to be considered here, only the coal and its roof are concerned. More or less of the coal has disappeared and occasionally the apparent replacement extends even to the underclay. Seen in cross-section,

the foreign material tapers downward as if introduced from above. Often there is no serious distortion, and the coal shows only such irregularity in structure and composition as might be expected if the process of accumulation was more or less interrupted. The variation in the coal is usually such as to indicate that the "trouble" had its origin, at the latest, before the coal was consolidated; but this is not always the case. At the same time, one must not fail to recognize that many times there are disturbances in the immediate proximity, which appear to be directly related to the "washout"; irregular cracks and faultings frequently occur, and the cracks are filled with clay from the partings or even from the "washout" stuff itself. These conditions are due to disturbances of later date; the effect of the force, which caused the gentle folding of the strata, became especially distinct where the mass of resistant rock had been thrust into the brittle coal.

Blandy<sup>123</sup> has described the conditions observed in the Red Bank Mining property in Armstrong county of Pennsylvania. The work of removing the coal from these mines had been made unprofitable by "horsebacks," as the miners termed the rolls of indurated clay descending from the roof. These seldom reached the floor but very frequently and for considerable distances, replaced all but 3 or 4 inches of the coal. It was necessary to ascertain the extent of these troubles before reaching a decision respecting farther continuance of operations. Blandy's systematic survey yielded the results presented on the map, which accompanies his paper. These "troubles" mark ancient water-courses. The chief stream was followed for about 1,700 feet and several well-defined branches were mapped. At the southerly end of the workings, another stream was encountered, nearly 100 feet eastward from the former. These stream-courses diverge northwardly, so that at the boundary of the property they are 1,200 feet apart. In another mine, somewhat farther east, the course of a third stream was followed for more than 600 feet, its branches being traced to varying distances. This stream curved

<sup>123</sup> J. F. Blandy, "On Evidence of Streams During the Deposition of the Coal," *Trans. Amer. Inst. Mining Engrs.*, Vol. IV., 1875, pp. 113-116.

toward the west in its lower portion, so that if the direction were retained, it would be continuous with a tributary of the main stream within less than 900 feet. Several branches were followed to their heads; in each case the channel became shallower and at length disappeared in the roof. At the sides of all the channels, one finds interlocking coal and clay and the adjacent coal is always tender, finely fractured but pure. The indurated clay, filling the channels, passes upward into shale.

Platt<sup>124</sup> has described a complicated channel of this type, seen by him in Westmoreland county of Pennsylvania. A "rock fault" in the Millwood Colliery on the Pittsburgh coal bed was traced for more than 1,200 feet. The roof is a grayish clay shale, which, at the edge of the "fault," descends suddenly through the bed and spreads out on the underclay. The sides slope at 20 degrees and upward. The width of the clay deposit averages 100 feet, but in one cross-heading the maximum, 120 feet, was found. Along the median line, wedge-shaped masses of the Pittsburgh sandstone replace part of the clay. Coal is found in the clay at the sides but not elsewhere. Close to the fault, the coal is twisted, hard, lusterless, and has so much slate as to be worthless for fuel. This condition changes gradually away from the clay and at 400 feet the coal equals that from other mines in the region. This description by Platt is that of a filled channel, originally occupied by a stream during the whole period of the Pittsburgh coal, a stream subject to floods and carrying muddy water which left its silt on the vegetation during overflow. The stream became insignificant during deposition of the overlying shale and its narrowed channel was obliterated during the early stages of the Pittsburgh sandstone. Similar "washouts" occur in other mining properties within the district, but their relations have not been worked out.

Descriptions of such channels abound in the reports in several states. Ashley and Udden have recorded instances like those of southwestern Pennsylvania, where the old channel way was filled with a conglomerate mass of pebbles, lumps of clay and coal, with

<sup>124</sup> W. G. Platt, Sec. Geol. Surv. Penn., Rep. H4, 1878, pp. xxv, xxvi.

stems and branches of trees. The "horse," about which Buddle<sup>125</sup> wrote many years ago, belongs in this category. This "washout," 170 to 340 yards wide, had been traced for about 2 miles in Colford High Delf seam. The material is sandstone, through which a tunnel had been driven where the width is about 200 yards. Under this "horse," the coal is 4 inches to 7 feet thick and usually it is injured by sand patches from the roof; but it contains no gravel, bowlders or fragments, though the last occur in the sandstone. Some portions of the "horse" consist of sandstone breccia, with pebbles of quartz, like those of the Forest pudding stone—which underlies the Carboniferous limestone—with fragments of coal, ironstone and plant remains. The underclay is wholly regular.

It is unnecessary to cite additional instances. The phenomena are familiar in British, French and German coal fields. They have been observed in the Laramie area of Colorado and New Mexico, and they are characteristic of the vast peat area of the Rhine lowlands, where they have been described by Lorie. All are alike, whatever the age may be; they are the work of sub-aerial streams, some of which existed while accumulation of the vegetable material was in progress, while others began existence at a later date.

#### FLEXED STRATA.

The presence of flexed shales or coals between beds of undisturbed rocks has been regarded as evidence of slips or slides of soft material on submerged slopes; but they cannot be accepted as evidence of such conditions until, first of all, the existence of the supposed conditions has been proved in other ways: for this structure is so familiar as to be almost normal in all strongly disturbed areas—in the Appalachian basin, in the Nord basin or in the little basin of Commentry. To bring about the condition there must be a soft, yielding material between beds of more resistant rock. Lohest<sup>126</sup> has shown that movements occur in the coal without disturbance of

<sup>125</sup> J. Buddle, "On the Great Fault called the "Horse" in the Forest of Dean Coal Field," *Trans. Geol. Soc. Lond.*, II., Vol. VI., 1842, pp. 215, 218.

<sup>126</sup> M. Lohest, "Sur le mouvement d'une couche de houille entre son toit et son mur," *Ann. Soc. Géol. de Belgique*, Vol. XVII., 1890, Mem., p. 125.

the roof; one notable case being that of the couche Grande Moisa, near Liège, where the coal is so distorted as to be thrown into a succession of hook-like curves. Briart<sup>127</sup> has given illustrations of similar movements in coal beds of the Nord basin. He had observed the phenomenon also in Italy just beyond the Austrian border. There one finds boghead, with clay beds, between great strata of dolomite, the latter showing throughout the section a remarkably regular dip of 30 to 40 degrees. Aside from this dip, they show no signs of disturbance, but the intervening, yielding rocks have been thrown into complicated folds. Katzer<sup>128</sup> notes a peculiar case; the upper part of a coal bed has been pushed into complex wrinkles, which occasionally affect the whole bed; but there are no wrinkles in the roof. Strahan,<sup>129</sup> in referring to a contorted clay parting between undisturbed benches, remarks "obviously the shale acting as a lubricant, has permitted differential movement between the strata above it and those below it." The explanation is manifest everywhere and is not open to dispute.

#### THE HYPOTHESES.

The reader who has examined Part I. of this work has discovered that, in most cases, an author regards his hypothesis as wholly satisfactory, as explaining all phenomena deserving explanation. The allochthonist greets joyfully each occurrence of pebbles in coal, of land shells in the rocks, of rooted stumps filled with sand, etc., as so much additional evidence in favor of his doctrine; while the autochthonist is equally elated by such occurrences, which are infallible proofs that his doctrine is correct. Observations at given localities are often contradictory, but there is no reason to assume that any observer has asserted, knowingly, an untruth or suppressed, consciously, a truth; yet it is clear that, in some cases, personal equation has played an important part, there being, apparently,

<sup>127</sup> A. Briart, "Notes sur les mouvements parallèles des roches stratifiées," *ibid.*, pp. 129-135.

<sup>128</sup> F. Katzer, "Notizien zur Geologie von Böhmen," *Verh. k. k. Reichsanst.*, 1904, pp. 150-159.

<sup>129</sup> A. Strahan, "Geology of South Wales Coal-Field," Part V., 1904, pp. 65, 66.

strong elective affinity for facts of one type in preference to those of another. At the same time, when one finds that the hypotheses are wholly antagonistic, he is compelled to believe that some must be wrong, and he is led to suspect that the best may be defective.

In considering the several hypotheses, the writer will take for granted that, as the laws of physics are unchangeable, physical agents have always acted in the same way as now, though at times their activity may have been greater and more prolonged than at others; That a hypothesis, to be acceptable, must not be based on assumptions, which are themselves hypothetical or not conceivable in terms of conditions actually known to exist; That inasmuch as knowledge is still imperfect, no hypothesis, satisfactory in all details, can be framed and that there must remain many matters to be studied by investigators in the future. There is no assertion of uniformitarianism beyond that of physical law.

Defenders of the several hypotheses should meet on equal terms in respect to introduction of evidence. Advocates of one group of hypotheses must not arrogate to themselves the right to utilize one type of evidence while denying that right to their opponents. It is hardly legitimate to denounce as tyranny the doctrine of Modern Causes, on one page, while on a later page of the same memoir, a luckless adversary is swept from the arena by the contemptuous assertion, that nothing of the kind is known in recent times. It must be remembered that, in this study, both inductive and deductive reasoning are required. No man ever explored the Carboniferous forests, mapped Carboniferous topography or sailed a Carboniferous sea. Those who defend the doctrine of Ancient Causes, equally with those who defend the doctrine of Modern Causes, reason from the known present to the unknown past. The starting point is absolutely the same for all. Evidence of every kind must be welcomed and an effort made to determine its value. Stratigraphers may not reject the testimony of palæontologists nor may the palæontologists speak slightly of the stratigraphers. For either group to dwell lovingly on errors of the other, committed many years ago, is as absurd as is the effort to discredit the work of modern Egyptologists because their predecessors of half a century ago, in their anxiety to reconcile

Egyptian chronology with that of Ussher, committed themselves in blunders now regarded as ludicrous.

In presuming to discuss conclusions reached by fellow-workers, the writer makes no pretence to superior judicial capacity; during the progress of this work he has discovered only too many proofs that his knowledge is defective, his judgment fallible and his mind on the defensive against novel conceptions. His conclusions are merely opinions based on extended observations in many lands during more than 40 years, and on careful study of literature bearing on all sides of the case. They are offered in the hope that they may prove to be of service to some student in the future.

Hypotheses presented to explain the formation of coal beds fall naturally into two groups; one asserting allochthonous origin of the plant material, the doctrine of transport; the other asserting autochthonous or *in situ* origin of that material. The former conception is the older.

#### ALLOCHTHONY.

The earliest observers, for the most part, saw in the rocks records of only cataclysmic action; for them, proofs of the Noachic deluge exist everywhere. In cosmogonies from the sixteenth to the nineteenth century, that flood is supposed to have covered the globe as a universal ocean, lashed into fury by winds, so that it tore away forests and bared the mountains; the whole mass of débris was swept into maelstroms, spread over the whole surface and, at length, deposited under selective influence of gravity. The majesty of the catastrophe had grown with the telling, and descriptions had become so vivid that the pictured conditions seemed to be reality. But the ravaging disaster was, in greatest part, imaginary; the Hebrew<sup>180</sup> chronicle relates nothing to enforce the conception. It describes the deluge as merely a rain flood, which destroyed animals by drowning but did not destroy the trees. There is no assertion of violence, for the clumsy ark drifted at ease throughout, the occupants resting apparently in comfort. The idea, however, was normal; all were familiar with the power of rushing waters, so that there was needed

<sup>180</sup> Genesis, Chapters VII., VIII.

only a conception of greater torrents in greater areas to give basis for hypotheses respecting the origin of rocks.

The doctrine of flood action was well-outlined at a very early date. Woodward, at the close of the seventeenth century, had announced that materials, swept from the land, sank to the ocean bottom in the order of their specific gravity; this was emphasized by Scheuchzer, Conybeare and several later writers, but it was disputed earnestly by Williams, as not in accord with the actual succession of strata. Applied to coal, modifications were made as acquaintance with the phenomena became more intimate. Some authors, Voigt, Parkinson and, much later, Petzholdt, thought that the vegetable material had been reduced to fluidity on the land before removal by floods; Sternberg and Boue held much the same opinion, for they thought that vegetable materials had been reduced to a pulp before removal and that the change to partial fluidity was produced in the tepid waters of the *primaeval* globe. Conybeare apparently was the first to conceive that a single flood might give materials for a coal bed of any thickness, and Jukes was the first to suggest that coal beds may have accumulated on the slopes of a submerged delta. But in all, one finds the conception of floods, carrying at one time mingled organic and inorganic *débris*, at another, mostly plant materials, but at a third, mostly inorganic substances.

Before undertaking the consideration of *allochthony* as a doctrine, it is well to examine several hypotheses, which have been defended by some eminent *allochthonists* but opposed energetically by others.

Mohr in 1866 revived suggestions by Parrott and Bischof that some coal beds might be accumulations of seaweed, and made them into a generalization respecting all coal beds. His reasoning is without reference to the conditions in which coal occurs; the mass of seaweed is incredibly great; there is enough to account for the coal; what has become of it? it has been converted into coal.

But there are some things needing explanation, with which Mohr does not concern himself. The mass of seaweed on the coast of France, Ireland and the Orkneys is enormous and, in all probability, it has always been so since the present climatic conditions began,

but, neither on those coasts nor on those of the North sea, does one find any considerable accumulations of decayed or decaying seaweed. The search in those areas has been rewarded by the discovery of a few deposits, which suffice to show the possibility of accumulation, while they emphasize the improbability. The ocean bottom has been dredged in all directions by exploring expeditions of many nations, but no trace of a deposit has been found in even the areas where seaweed is most abundant. Mohr thinks that the Spitzbergen coals owe their origin to weed transported by the Gulf Stream. There is sufficient reason for doubting the existence of that stream at the time when those coals were formed; but, in any event, if the stream were existing then and as efficient as now, it could not avail for the work. Robert's<sup>181</sup> statements respecting the quantity of weed on the Spitzbergen coast do not bear the interpretation placed on them by Mohr. There may be enough at times, if the wind be right, to make landing on the shelving shore a rather awkward process—it is awkward enough at best—but the quantity is wholly unimportant. Stevenson, in 1904, sailed along the west coast for 150 miles and saw very little seaweed.

In like manner, conditions within the Sargasso sea have been exaggerated. Wierd reports by crews of Columbus's boats, 18 to 40 tons burden, have been repeated with the increment of centuries and have found their way into geological treatises everywhere. Stevenson<sup>182</sup> made two voyages in 1910 across the central part of that sea, where the mass of weed should be densest. The quantity, from the standpoint of Mohr's hypothesis, is utterly insignificant. At times, small patches, perhaps 100 or even 200 feet square, may occur, but they are rare and have brief existence, as they are broken up quickly by the strong trade wind, which keeps the water in constant commotion—the surface being covered almost without cessation by "white caps." The feathery individual bunches of weed, rarely more than 1 foot in diameter, are arranged in lines following

<sup>181</sup> E. Robert, "Aperçu des observations géologiques faites dans le nord de l'Europe," *Bull. Soc. Géol. de France*, Vol. XIII., 1842, pp. 24, 25.

<sup>182</sup> J. J. Stevenson, "The Sargasso Sea," *Science*, N. S., Vol. XXXII., 1910, pp. 841-843.

the direction of the wind. Occasionally, several lines are united into a strip, 5 or 6 feet wide, but the bunches are barely in contact, while spaces of 500 to 2,000 feet intervene between the strips. Within the area, where weed is most abundant, the whole mass, in a width of a mile, would form a strip not more than 65 feet wide, if the bunches merely touched; if the material were compressed, so as to bring the parts of each bunch into contact, the strip would be insignificant, not more than 2,500 cubic yards to the square mile. North and south from this small central area, the quantity of weed is unimportant.

Ochsenius<sup>133</sup> in 1890 made some suggestions, which in later publications he developed into what is known as the "barricade theory." This has been given in detail on earlier pages in Part I. One might hesitate to regard this "theory" as offered seriously; but its author presented it in various forms and discussed it elaborately; some geologists have considered it worthy of refutation, while others appear to have found in it enough of suggestiveness to give it merit. Ochsenius clearly was not familiar with conditions observed in coal deposits and his information respecting river action was imperfect. He cites the statements of writers concerning various localities, but these refer to matters quite irrelevant. The rafts of the Atchafalaya and of the Red river have no bearing upon the question of his dams. The extent and character of those rafts were grossly exaggerated by the early observers, but such as they were, they could not be formed on the rivers imagined by Ochsenius, as they required an enormous drainage area. Of course, barricades could be formed at curves of rivers and they are formed; but they are not such as the "barricade theory" demands. Such a blockade of timber would soon become a dam without lateral spillway, as he suggests; but if it existed long enough, with low water, to permit the fine "Spulgut" passing over to form a bed of carbonaceous shale in the basin, and long enough afterwards, with continuous high water, to permit

<sup>133</sup> C. Ochsenius, "Ueber das Alter einiger Theile der (süd-amerikanischen) Anden. III.," *Zeitsch. deutsch. geol. Gesell.*, Vol. XLII., 1890, pp. 135, 136; "Die Bildung von Kohlenflötzen," *ibid.*, Vol. XLIV., 1892, pp. 84-86, 98; "Die Bildung der Kohlenflötze," *Verh. des. d. Naturf. u. Aertze*, II., 1896, pp. 224-230.

coarse "Sperrgut" to pass over so as to form a coal bed in the basin, it would be no longer a mere dam: it would be a deposit in the channel-way, miles long, which would be impregnable against any flood: the mighty débâcle, which would sweep out the dam and all accumulated material behind it, the "Rollgut," to make a sandstone and conglomerate deposit in the basin, is beyond the reach of imagination. Being in a lowland, little above sea-level, there could not be any such flood as Ochsenius conceives, since high water would give only a comparatively harmless overflow. But at best, the obstruction would cause the river to seek a new channel-way. That was the effect of the Red river raft; the Sudd of the Nile, overturned trees blocking the channel of the Bermejo in Paraguay, obstructions along the upper Mississippi do the same thing; they are not swept out by the high floods, they merely cause diversion of the stream. The breaking of levees along the Mississippi has no bearing on the matter. Those structures have a moderate base in comparison with their height, whereas the barricade, after centuries of accumulation, would be only a few feet high and miles long.

Jukes saw in the Coal Measures of the South Staffordshire field deposits resembling those on a submerged delta cone; his arguments have been presented on an earlier page. Almost a quarter of a century later, Fayol, after long study of the Commentry coal basin, reached similar conclusions, which, in 1888, he presented in such admirable form, with such skilfull attention to detail and with such apparent grasp of all the features and possibilities, that his conception won instant approval from many eminent geologists in all lands and it was accepted as a final explanation of phenomena in the limnic basins of central France. This "Delta theory" merits careful consideration.

According to Fayol, the basin of Commentry was occupied by a lake, 9 kilometers long and 3 kilometers wide, with greatest depth of 800 meters and with an outlet on the southern border. Rain water ate away the surrounding mountainous region and the transported materials are those composing the beds of conglomerate, sandstone, shale and coal now filling the basin. The distribution of those materials was determined by their specific gravity or their

fineness of grain as well as by the condition of the water—quiet or agitated. The finer, lighter materials were carried much farther than the others before reaching the bottom. The basin was filled eventually by detritus from the Colombier at the northeast, the Bourrus at the north and by several less important streams at the north and west; these giving three “zones” of coarse material without coal. Between those “zones” and separated by the Bourrus deposits, are two areas of less coarse deposits, les Pegauds at the east and les Ferrieres at the west, in which the coal beds are found. Petty streams from the north added their quotas, uniting the deltas along the northern border, but practically no material was brought in from the south. The streams were, all of them, short and torrential. The delta-character of the mass is shown distinctly in the Pegauds area by the steep dip of the beds, which approximates closely that of neptunian or submerged portions of deltas; by the presence of fragments of coal, shale and sandstone in the rocks proving gradual advance of the delta-plain; by slips, of which the proof is seen in folded shales, local faultings, evidence of movements of yielding materials on a steep slope; by local erosions; by the clear evidence of great débâcles; and by the structure of the coal beds, which are not parallel. The absence of horizontal alluvial beds on top is due to gradual deepening of the outlet, which amounted to about 100 meters at the close of deposition. Fayol makes no reference in his work to the Decazeville basin, but, as stated in the report of the Réunion of the Geological Society, his theory was applied to that basin by others, who found the evidence as conclusive as that in Commentry.

In considering this doctrine, one must bear in mind that the matter does not concern the existence of deltas in lakes, for that has never been disputed. Nor does it concern accumulation of vegetable materials in one way or another on the alluvial deposits of deltas, for that too has never been disputed. Fayol's doctrine is that coal beds, like other transported materials, were deposited as part of the neptunian or submerged portions of deltas. Granting, for the present, that vegetable matter to give such coal beds could be brought in by the streams, the only question for consideration here is,

whether or not the phenomena at Commentry and Decazeville justify the conclusions embraced in the Delta theory.

The dips of the strata at Commentry are regarded as all-important evidence, since in much of the area they compare with those observed in some lake deltas. But it must not be overlooked that the steep dips, 20 to almost 50 degrees, are those in the Pegauds area, in the supposed bay between the Bourrus and Colombier deltas. Before formation of the Grande Couche, the Bourrus delta had practically crossed the basin, dividing it into two little ponds, of which the eastern or larger may have had an extent of rather more than 2,000 acres. The coal is on the northern border of this pond or bay, while the outlet was on the south side of the basin. The area of the steep dips is nearly 2 miles from the spot where the Bourrus issued from the mountains and three-fifths of a mile west from the coarse rocks of the Colombier deposits. Its rocks are shales and fine-grained sandstones. It is not on the steep delta slopes, but in the quiet "eddy" between the deltas. The dips in such an area should be gentle, not abrupt. Martins states that, within three-fifths of a mile, the slope of the Aar delta in Lake Brienz decreases from 30 degrees to practical horizontality; De la Beche found the Rhone delta practically horizontal at 2 miles from the shore, while the delta of the torrent of Ripaille, formed in deeper water, showed not more than 10 degrees as the average for half a mile. In every case the decrease is very rapid away from the source of supply and the dip is usually quite gentle within less than a mile, though often very steep at the origin. It would be impossible to explain the steep dips in the Pegauds area, if they be taken as original. But one is not left to surmise in order to explain these dips, for they are not original.

The cause is clear enough; they are due in chief part to disturbance accompanying an outburst of eruptive rock in the northeast corner of Pegauds. This affected not only Pegauds but also the Ferrieres sub-basin, about 3 miles toward the west. This outburst took place when the deposition of Coal Measures rocks had been completed and prior to that of the Permian, which is unconformable. This disturbance crushed sandstones and flexed soft shales between

sandstones ; in some places it shattered the coal and rubbed the fragments to polished surfaces, at times reducing the coal and shale to a flaky structure like that of pastry. The conditions are those so familiar in the Logan and Pottsville coal areas of southwest Virginia and southeastern Kentucky, as well as in the Allegheny area of Broad Top in Pennsylvania. They are commonplace in some Cretaceous areas at the west. The extent of disturbance increases toward the place of greatest outburst, where one finds faults and slips in abundance. The remarkable "*Glissement de l'Esperance*" is in no sense due to a slide on the slope of a submerged delta. This *glissement* marks the course of a valley, eroded after the Coal Measures deposition had been completed. It was filled with materials different from those of the adjacent rocks and extended for a considerable distance toward the southeast. Similar material was seen in a fragmentary exposure along the railroad at about 3 miles northwest. When the eruption took place, these new, light-colored rocks of the valley were folded into a close irregular syncline, the finer dark shales of the valley wall were pushed over into recumbent folds and a sharp horizontal fault was made underneath the syncline ; other valleys of similar type were observed in the basin. The structure, in its striking features, is in no wise original and has no bearing whatever on the mode of deposition.

Practically no coal in economic quantity was formed in the Comentry basin until after not less than 500 meters of rock had been deposited. Suddenly one comes to the *Grande Couche* in les Pegauds, with maximum thickness of not less than 12 meters, and to a similar bed with greater maximum in les Ferrieres—the other and smaller sub-basin. This abrupt appearance of the great coal deposits is a phenomenon for which the delta theory offers no adequate explanation. The streams had brought down a marvelous quantity of inorganic material, converting much of the lake area into dry land and, of necessity, making much of the still water-covered area very shallow. But during this period, no vegetable materials had been brought down, aside from those composing the insignificant streaks of anthracite along the northern border. The new land on the northern side of les Pegauds, barely half a mile

wide, could not have provided material for the coal, as, only a few years earlier, reckoning time as is done in the *Études*, it had been the scene of a terrific débâcle, which had swept 125,000,000 cubic meters of rock across it and had left the surface strewn with coarse debris. It would seem as though vegetation must have appeared abruptly throughout the drainage area or that the streams must have changed their methods quite as abruptly, so as to devote attention to plants instead of to inorganic materials.

Aside from this, the theory seems to offer no satisfactory explanation of the areal distribution of the coal. Even though the lake had been as deep originally as conceived by Fayol, the pond must have become comparatively shallow prior to formation of the Grande Couche, and the bottom must have fallen off quite gently as it receded from the shore line at the north. One cannot conceive, after reading Fayol's description of the region, that any other condition was possible. The Grande Couche is on this northern border of the Pegauds area, and its present outcrop is less than a mile south from the granite. The outcrop is shaped much like a spreading horse-shoe, with its convexity toward the north. The bed is very thick on the north side of the curve but breaks up into several beds at the west, where it disappears, whereas on the east side it merely thins away. Southwardly, it quickly loses thickness, breaks up and within a short distance it disappears. It is confined to that portion of the area where, of necessity, the water was shallow. There is no evidence of any sort that the water was deep; it will not suffice to assert that the presence of tree-trunks in the coal proves that there was an eddy here and that therefore the water was deep; that is merely an assertion that the fundamental assumptions are true. The presence of those tree-trunks in such wonderful abundance, can be utilized to prove that the doctrine is defective. But that is unimportant; if the conditions were as described in the *Études*, the water was shallow in the area now occupied by the Grande Couche. The middle bench of that coal bed is about 10 feet thick for a considerable distance, very clean, and consists so largely of prostrate tree trunks that it must represent a mass of transported vegetation which could not have been less than 150 feet thick. It is so free

from slaty admixture as to suggest that, during its formation, the streams brought into the area practically no inorganic material. It rests on the Banc des Roseaux, a sandy deposit literally crowded with stems and trunks, and extending apparently no farther than the coal in any direction. The purity of the coal shows that the whole mass was brought down at once, and it is at the head of the recess between the Bourrus and Colombier deltas—where neither it nor the sandy bed below should be.

A flood, so terrific as to sweep such a mass of vegetation from the little drainage area, could not be confined to the head waters of the Bourrus and Colombier; the other short streams between them would also be in flood, pouring their great contribution of water into the pond. There could not be any eddying; the whole surface of the water would be dashing with its load toward the outlet. If that were blocked, much of the deposit would be made along the southern border. But, even conceding that the trees were not deposited there, one must not forget that floods of the supposed violence are of brief duration and that floating wood remains very long time before becoming waterlogged. The surface movement would be steadily toward the outlet; there is no conceivable manner whereby the enormous mass of trees could be pushed against the current so as to be deposited at the head of the pond, where the water was too shallow to float the raft not less than 150 feet thick. But aside from this, the coal is not where it should be. According to the law of deposit on a deeply submerged delta cone, coal should be found crossing the cone in curved lines and it should thicken in the direction of the finer sediments. But there is no coal curving across the Bourrus delta; the coal of the Grande Couche disappears in the direction of finer sediments.

Conditions in the Decazeville basin bear no resemblance to those in the Commeny basin. The relation of the coal beds to old river courses and the variations in thickness are wholly different. The theory that coal beds were deposited on the slopes of submerged delta cones does not account for the conditions observed in those basins; Grand'Eury and Gruner found that theory inapplicable to

the Loire basin. Its author did not assert that it could be utilized to explain conditions in paralic areas, but he evidently expected to find support for it in those also. It is fully evident that it has no application whatever to the Appalachian basin, where the rocks were deposited in horizontal condition. Even now, they are almost horizontal in areas of many thousands of square miles within Ohio, West Virginia and Pennsylvania, where for long distances the dip is from one fourth to one half degree—and this dip is not original, for the region was affected by the Appalachian revolution and the beds were flexed. One nowhere finds any evidence of the submerged, steeply dipping beds of a delta; but the thousands of oil-well records show conformity throughout the Coal Measures column—aside from the variation due to local conditions or to widespread differential subsidence.

The term "Delta theory" is an unfortunate misnomer. "Delta," as ordinarily understood, designates not merely the submerged cone but also and chiefly the horizontal, alluvial deposits, and it at once suggests conditions observed in the lower reaches of great rivers, where the neptunian beds have very gentle slope. But this doctrine concerns only deposits made in small bodies of water by short torrential streams. The formation of a cone, such as the doctrine requires, would be possible only if the water were very deep and the bounding wall precipitous where the streams enter. There is no evidence that the conditions existed. No fault is known on the northerly side, but a limiting fault is indicated on the southerly side of the Commentry basin. There may have been important accumulations of water, at times, due to blocking of the exit or to depression along the fault, but such disturbances could have been of only brief duration. The conditions at Commentry resemble very much those observed along the Upper Rhone, and the writer is inclined to regard the "deltas" of the Bourrus and Colombier as alluvial fans.

Some of the "deltas" in the Decazeville basin have all the characteristics of alluvial fans and the deposits show distinctly the selective action of running water; but there are others which are not due to stream action. The great granite conglomerates, with huge

blocks encased in coarse to fine granitic sand, are merely disintegrated granite, the same as that which one sees at many localities between Montluçon and Decazeville. This is much like the great deposit underlying the Mesozoic coal area in Virginia, described by Shaler and Woodworth.<sup>134</sup> The writer could discover no evidence that a deep body of water occupied the Decazeville basin at any time, but there is abundant evidence that the water area was never extensive, except possibly toward the close of deposition.<sup>135</sup>

The doctrine of allochthony is not bound to the hypotheses which have been considered, for some of its defenders have no patience with either the Delta or the Barricade theory. The essential feature of the doctrine is, that vegetable matter growing on the land was removed by running water and deposited in water-basins, there to become coal; but there are individual differences in detail. Woodward, Scheuchzer, Conybeare, Buckland, Murchison, Fayol, de Lapparent, Renault, Ochsénus, Lemièrè and Stainier believe that the work was done by energetic floods; Grand'Eury and Sterzel see no proof of devastating floods, but appear to regard great rains and mild floods as sufficient; while de Jussieu, Buffon, Hutton, Faujas-St.-Fond, Naumann and Jukes do not concern themselves with the work of transference, but deal only with distribution after materials have reached the water-area. But for all, the principle of distribution by gravity holds an important place. One author puts the matter compactly. Coal plants grew on continents bordering great depressions, into which the meteoric agencies carried vegetable débris along with materials torn from the land by erosion. As calm was restored, the materials went to the bottom in well-defined order, determined by density; sandstone first, then the mud, then the coal and, finally, impalpable clays reached the bottom to form the roof.

Many authors appear to be convinced that all portions of a

<sup>134</sup> N. S. Shaler and J. B. Woodworth, "Geology of the Richmond Basin, Virginia," 19th Ann. Rep. U. S. Geol. Surv., 1899, Part II., Pl. XXI.

<sup>135</sup> J. J. Stevenson, "The Coal Basin of Commeny in Central France," *Ann. N. Y. Acad. Sci.*, Vol. XIX., 1910, pp. 161-204; "The Coal Basin of Decazeville, France," *ibid.*, Vol. XX., 1910, pp. 243-294.

vertical section must have been formed after the same general fashion. Surprise is expressed because coal beds are believed by any one to have an origin different from that of the sterile beds enclosing them; the presence of marine deposits in a column is evidence that the whole column owes its origin to transported materials. But there seems to be little ground for any generalization of this kind. It can hardly be accepted as accurate for a single bed, though it has been so applied. Perhaps Fayol's statement is the best illustration. He had proved that sandstone and shale are composed of materials transported by running water and that the enclosed fragments of plants had also been transported; shales and sandstones, by increase of plant remains and decrease of inorganic materials, become carbonaceous and, in some cases, pass into coal beds; community of origin throughout is clear. But there is a wide gap here between premises and conclusion. The latter is possible, even probable in some cases, but it cannot be accepted as a generalization, for the contrary is a familiar condition in actual peat deposits, where one often finds all possible transitions from sand or clay, on the border, through sandy or clayey peat to the clean peat accumulating beyond. The general assertion, when applied to a succession of deposits, seems to be equally inexact. Alternations of peat with marine deposits are frequent on the coast of the German ocean and English channel, and some of those peats are continuous with living bogs farther inland. Peat in the Bermudas rests on marine limestone and underlies aeolian limestone. In the same region, one may see a living coral reef, formed on submerged aeolian limestone and now in process of burial under aeolian limestone. A forest in Alaska still remains *in situ*, though a great thickness of transported sands and gravels has accumulated around the dead trunks. On many coasts, forests, submerged for centuries, are still recognizable, though material from the land has almost buried them. Borings in deltas and in river plains show that within a vertical distance of 300 feet one may find land, freshwater and marine deposits.

Distribution of deposits by selective influence of gravity is a very alluring suggestion, especially to those who believe that deposits

can be made only in a considerable body of water—itsself a conception which is in great need of proof. But one must concede that it involves many and serious difficulties in its application to small areas, such as the Commentry and Loire basins, and still greater difficulties when larger areas are considered; the more so when one remembers the proposition presented by some eminent men, that a bed of coal may be the product of a single flood.

Taking the Commentry basin as typical for small areas, one finds that coal accumulation began there only after not less than 500 meters of inorganic deposits had been laid down and a considerable part of the area had been converted into land. The two ponds, Pegauds and Ferrieres, were separated by the barren zone of Montassiégé, débris from the Bourrus torrent. The areas of those ponds were perhaps rather more than 2,000 and 1,000 acres respectively. The floods leading to formation of the great coal beds on the north shore of those ponds were extreme; trees were carried down and deposited with the sands in all directions, erect, inclined, prostrate and, in at least one instance, upside down. The vegetable cover was stripped from the drainage area and the whole mass was swept along narrow gorges through which the torrential streams flowed. This conception of the violence is not excessive; nothing less could do the work; for one must remember that the streams were still young, their gorges had been cut in granite and gneiss; the course must have been tortuous and the beds irregular, with shoals and rapids. When this vast mass of débris reached the water-basins, deep or shallow, they would be churned up by the flood's mad rush for the outlet, through which the water would pour with the force of a lake Bagne débâcle, carrying with it the finer and much of the coarser materials. There could be no selection under the influence of gravity. The Banc des Roseaux, dividing the Grande Couche, contains trees in great abundance, supposed to have been brought down by the streams; no selection was there, for the deposit is not along the main stream line of either Bourrus or Colombier, but in the supposed bay between the deltas. It might be suggested that the flood exercised its selective power before beginning the downward course.

In applying the doctrine to larger areas, defenders of allochthony find many illustrations which they regard as more than important. Much is said of timber rafts on great rivers, the masses of floating vegetation on the Amazon, Congo, Orinoco and other great streams, the rake at the outlet of lake Tanganika, the dredgings by A. Agassiz, the accumulation of drift wood on many coasts and the distributing power of currents. But it is not easy to discover what bearing any or all of these can have upon the formation of a coal bed with its orderly succession of floor coal and roof.

The timber composing the Atchafalaya raft was gathered from caving banks along more than 20,000 miles of river courses; very little of it was contributed by floods. Neither the Atchafalaya nor the Red river raft was a solid mass; each was in patches, separated by considerable spaces of open water. If they had sunk to the bottom, no coal bed would have been formed, there would have been only a mass of sediment enclosing logs. And this was the actual condition discovered, when the floating portion of the Red river raft was removed. But, in any event, the statements respecting the extent and character of those rafts, found in many publications, have been proved to be fabulous. If those statements had been true, if trees 60 feet high had grown on the Atchafalaya raft, those very statements should have restrained allochthonists from utilizing the rafts in their defense, since they go to show the immensely long time required to convert timber to the sinking condition and to show also the great amount of inorganic matter entangled in the rafts. Reference to descriptions<sup>136</sup> by competent observers will be sufficient for the reader. The same remarks apply to all accumulations of driftwood. As has been shown on earlier pages, the observations by uncritical voyagers were inexact; photographs prove that driftwood on coasts occurs in scattered fragments, occasionally collected into loose piles. On the shores of lakes or bays, the wind often drives considerable quantities into masses, upon which waves toss sand or silt. McConnell's detailed examination of driftwood deposits on Lake Athabasca made the conditions clear and showed how erroneous were the conclusions drawn from Richardson's description. Con-

<sup>136</sup> "Formation of Coal Beds," II., these PROCEEDINGS, Vol. L., pp. 548-551.

sidering the extent of area whence driftwood has been drawn, the quantity stranded on coasts is remarkably small. It has been gathered by great rivers of America and Asia to be distributed by currents, which have originated since the Carboniferous.

Conditions on the Amazon, Congo and other tropical rivers lend no countenance to the assertion that great sheets of floating vegetation might have been brought down by rivers into estuaries to aid in formation of coal beds. Those great streams, in time of flood, unquestionably carry matted vegetation in considerable quantity. Earlier pages of this work contain descriptions by travellers, which show little tendency to scientific accuracy, but suffice to prove that the material, thus transported, is far from insignificant. At the same time, granting that strangeness of the phenomenon did not lead the traveller to exaggeration and granting that the statements do not tell even half of the truth, the relevance of the occurrences may well be questioned. No reason has ever been presented to justify a suggestion that streams, such as have been named, could have existed as tributaries to estuaries, in which one now finds the Westphalia-Nord coal basins; nor is there any ground for supposing that if they had existed, they would have carried the imagined sheets of plant materials.

It is difficult to understand why the observations by A. Agassiz have been regarded as supporting allochthony, since they in no wise bear on the questions at issue. There was nothing novel about them except the localities. Every one knew that the muds of ponds and lakes contain twigs, leaves, pollen and spores as well as occasional larger fragments of wood. It was equally well known that the silts on river banks contain transported fragments of plants; that the Mississippi and the Orinoco deliver vast quantities of driftwood into the Gulf of Mexico and the Caribbean sea, and the devastating effects of West Indies hurricanes have been described by many writers. If the trawls had not brought up much plant material with the muds of the Caribbean and those off the California coast, the condition would have been inexplicable. But Agassiz found no evidence of a coal bed in process of formation, he found no evidence of sorting of materials through influence of gravity, he found no proof

of elective affinity inducing plant materials to flock by themselves. He did find mud containing much vegetable and other organic matter. His observations indicate only that much plant material carried into the sea does become waterlogged and does sink to the bottom; but they give no suggestion respecting formation of coal beds, although they certainly explain well some features of carbonaceous shale.

The doctrine of allochthony accounts satisfactorily for many phenomena observed in the coal deposits, such as the fragmentary remains of plants in the roof, the presence of drifted trees in sandstones, the occurrence of marine limestones and many others. But these are explicable quite as easily by autochthony, so that they need no further note at this point. Allochthony, as the writer understands it, offers no adequate explanation of the lamination in coal, which does not resemble that of sedimentation; it fails wholly to account for a structure such as that of the Pittsburgh coal bed, whose thin partings of mineral charcoal and mostly impalpable silt persist in an area of several thousand square miles; its assumption of distribution of sediments under influence of gravity fails when applied to the Appalachian basin, for there the coal, as in Commen-try and in other areas disappears with decreasing coarseness of sediments; it affords no means of explaining the remarkable purity of some beds which yield coal of very high grade throughout continuous areas of 2,000 to 7,000 square miles.

The fundamental assumption of allochthony is that rain and floods can remove the vegetable cover, living or dead, from land areas and can convey it to a water basin, there to be deposited and to become coal. This conception seems to be without foundation in actual conditions and to be based upon study of erosive processes in unprotected or disintegrated rocks. The effects of running water on a cover of vegetation were examined in Part II. of this work. It remains only to present the matter synoptically with reference to statements made in defense of allochthony.

It is well to restate the opinions offered by prominent defenders of allochthony, that there may be no misapprehension. Bischof thought that in the earlier times the land was more densely forested than now and that the streams carried off a much greater quantity

of vegetable matter. Grand'Eury, seeing evidence only of quiet deposition, did not recognize the agency of violent floods; the vegetable debris underwent disintegration and decomposition on the land whence it was removed by rain and ordinary floods. There seems to be no positive assertion in any part of Fayol's work that the floods were of extreme violence, but the torrential character of the streams and their great carrying power are essential features of his explanations. De Lapparent stated the matter with clearness, when he asserted that, in the Central Plateau, vegetable masses descended *en bloc* and were deposited as localized coal beds; so that a single flood might make a coal bed of any dimensions. Renault conceived that as there was no ice cap at the poles, the rainfall was greater, the floods more violent and the quantity of transported vegetable materials much in excess of the present, because the surface was covered with a vegetable growth surpassing that now found in the tropics. Lemièrre thought of deep lakes or lagoons fronted by vast low-lying plains; the contributing area was between the levels of low and high water; it was swept clear of vegetation during floods; a mass of vegetation removed *en bloc* might present the appearance of formation *in situ*; during low water, the streams would bring in little aside from inorganic materials. For Stainier, the plants grew on the continent, whence they were swept into depressions along with inorganic materials, the mass being assorted by specific gravity; the *Stigmaria* being denser, sank into the underclay.

The flooding of vast lowland areas is not hypothetical; the writer, in Part II. of this work, has cited many authors to show that, in the Ganges, Yang-tse-kiang, Amazon, Zambesi, Mississippi and other extensive drainage areas, great floods are only too familiar features; that for long distances, at times hundreds of miles, the lowlands are covered to the depth of many feet in strips 40 to 100 miles wide; the depth in some cases being such that only the tops of the highest trees can be seen. The water for these floods comes at times from highlands far away and is not that from rainfall over the flooded region; at other times, the storms originating in distant highlands pass over the area before the flood reaches the plain; but the characteristics are practically the same in all cases. The flood

is highest in the upper reaches, where the stream is narrower, but decreases in height where the flood-plain becomes wide, unless accessions have been received from tributaries. Floods of this type do not sweep vegetation from the flood-plain. If one accepting the transport doctrine in full should read of conditions in the Mississippi area with its several floods each year, 40 to 60 feet deep in various parts of the lowland region—sometimes converting areas of 10,000 square miles into inland seas—he would expect to learn that that region is in great part a dreary waste, deprived of vegetation and uninhabitable. But not so; it is the home of millions of people; it contains many cities with 50,000 to 500,000 inhabitants; a great part, which has not been cleared for cultivation, is still heavily forested, covered with ancient trees; even the swampy areas, subject to flood from long before settlement by man, abound in the majestic *Taxodium*. These floods lift buildings from their foundations and carry them away; they injure farming land by leaving a deposit of silt or sand; they disturb property relations by undercutting the banks or by digging a new channel across the necks of horseshoe curves; but they usually are of brief duration and normal conditions return.

Transportation of vegetable materials by streams is no matter of hypothesis. Every stream carries on its surface twigs and leaves torn off by the wind; rivers carry great quantities of coarse and fine débris, increased in times of high water by trees and shrubs from caving banks; but the cover of vegetation remains practically uninjured in spite of all attacks. Agassiz, Kuntze, Humboldt, Wallace and other travellers in South America; Merrill, Frankenfield, Humphreys and Abbot as well as other observers in the Mississippi area; Livingstone, Cameron, Baker, Stanley and other travellers in Africa; Medlicott, Blanford and others in India, all tell the same story, as has been shown on earlier pages. The lowland flood rises slowly, it does not scour the surface, it does not destroy the forest growth, large or small, it does not disturb the peat deposits. Even when loaded with cakes of ice, it is powerless against standing trees, as has been observed many times on rivers in the eastern states. The high-level line of floods is ascertained by noting the silt rings on

tree trunks—a method employed in South America, Australia and on the Pacific coast for semi-torrential as well as for lowland floods. The overflow flood, that portion outside of the channel, moves slowly at the bottom and does not scour; instead, it deposits inorganic materials. If forced aside into a narrow space, it may cut a channel; but in that case it has ceased to be a flood and has become a local current. These are characteristics of lowland floods everywhere; the movements of water are governed by the same law throughout the world; there is no reason to suppose that other laws prevailed during earlier periods, to be repealed abruptly at the beginning of the Quaternary.

The floods of torrents can hardly be regarded as supporting the doctrine of allochthony. In some features they resemble those on lowlands, but in many ways the phenomena are different. Ordinarily, torrents flow in narrow valleys, more or less gorge-like with here and there a petty flood-plain, on which trees grow. Some large rivers, such as the Potomac, Monongahela and others rising in the Appalachian chain, are torrential during flood in the greater part of their length, but differ from the ordinary torrent in the width of their valleys and of the wooded flood-plains. In all, the rapidity of flow suffices to carry off the water, with, at most, trifling overflow of the plain, the chief change being in the channel which may be widened or deepened. At ordinary stages, torrents, in areas of consolidated rocks, transport very little mineral matter and the water is the plain, the chief change being in the channel which may be very great. But the coarse material is pushed along the bottom, except in extraordinary instances, and comparatively little is carried over to the flood-plain. The rushing water does insignificant injury to trees or plants on that plain, in spite of great speed, as was shown well during the great flood of the Potomac. One can see this for himself along mountain torrents, where trees grow to within a foot of the ordinary water line. There are many such torrents in the central plateau of France, whose fierce floods have done no more injury to trees on their rocky walls than is done to trees by the lowland floods of the Seine area; only fallen stems and other unattached

débris are gathered up to be mingled with inorganic débris from the channel-way.

But there are floods, caused by cloud-bursts at the heads of streams with rapid fall in narrow gorges, which are destructive throughout. Such floods, loaded with coarse and fine rock material, scour the little flood-plains, removing soil and trees alike, the latter to be deposited with the mass of mineral débris in any or all positions, vertical, prostrate, inclined or reversed; and with them would be rootless stems broken off from the cañon walls. The condition is wholly similar to that caused by the bursting of a dam, as in the Johnstown or the Lake Bagne disaster. A torrent flowing in a gorge of gneiss or granite, especially if it be so juvenile as those imagined by Fayol and de Lapparent, would be a succession of falls and rapids, over which trees could not be carried unless the depth of water was such as comes from a cloudburst. It is deserving of note in this connection that plant remains occur very rarely in the Siwalik conglomerates, which, as described by Medlicott, were brought down by the fierce torrents of the Himalayan slope. The small quantity of vegetable materials in Coal Measures sandstones is a remarkable phenomenon, for sandstones certainly tell of greatly increased activity in the streams.

But it is evident from the statements by Fayol and de Lapparent as well as by several others who have been cited, that the supply of plant material comes not from immediate vicinity of the gorges but from the whole drainage area. The difficulties in the way of this suggestion are very serious. The upland region of Fayol and de Lapparent must have been covered with a forest, denser than any in the temperates and with an undergrowth like that of a tropical jungle. Renault goes farther and thinks the vegetation of those days more exuberant than that of the tropics at this time. This condition makes the asserted results impossible, so that the conception hardly deserves the exultant compliment by de Lapparent, that it is a triumph of common sense.

If the flood gates of heaven were opened and the flow of water concentrated on one spot so as to work underneath the vegetable cover, the whole surface would be stripped of soil and all else; but

there is no other conceivable set of conditions whereby the supposed cover of vegetation could be removed. The mass of more or less disintegrated and decomposed plant materials on the surface was very thick; rain falling on this would be absorbed and the material would be cemented. The roots of plants would resist movement of the water; those roots form a network which, under very unfavorable circumstances, suffices to check that movement; a handful of loose sandy clay on a sloping shelf in a railway cut is hardly diminished by a dashing shower or the accompanying rills, if only a bunch of grass have thrust its roots through it. How much greater would be the resistance of the dense vegetation, one can hardly conceive. It would be impossible for a flood to retain any force after encountering such a wall, even though the slope were somewhat steep and though the water had been ploughing the surface for some distance. The observations recorded by Marsh<sup>187</sup> make this sufficiently clear. Any one who has stood at the edge of a wooded river-bottom during time of high flood, knows that, no matter how the water rages outside, quiet reigns within that area and the overflow moves gently. Where vegetation is dense, no flood does damage. A flood can never gain speed in a rolling country covered with such vegetation as supposed by Renault and others; within the matt of plants it would be as powerless for injury as is a great mass of snow on a densely wooded slope. One cannot repeat too often or emphasize too strongly that running water does not strip off a vegetable cover, that floods do not uproot forests, do not tear away beds of peat. This has been shown in Part II. of this work. Be it understood there is no reference here to digging of a new channel-ways by *débris-laden* streams; or to such local accidents as disturbances of the vegetable cover by eddies around stumps or large boulders in an open area; or even to bursting bogs. Such accidents affecting a few rods or even acres, are very important to the farmer whose pet meadow has been ruined, but they are without interest to one studying conditions within areas of many square miles or along flood lines, scores to hundreds of miles long.

Allochthony applies one set of phenomena, occurring under defi-

<sup>187</sup> "Formation of Coal Beds," II., these PROCEEDINGS, Vol. L., p. 531.

nite conditions to the explanation of another set of phenomena, which are impossible under those conditions. It is in constant conflict with what seem to be the established laws in nature. The true explanation of the formation of coal beds may be still unknown, and it may be the lot of chemists, geologists and palæontologists to follow many paths of investigation for many years before discovering the truth; but, to the writer, it appears certain that the path marked by allochthony ends in a *cul de sac*, walled with contradictions; and that farther investigation along that path will be fruitless; for allochthony magnifies the exceptional into the normal and endeavors so to explain away the normal that it may appear to be the exceptional.

#### AUTOCHTHONY.

According to the doctrine of autochthony, the plants, yielding material for the coal, grew where the coal is now found; this is not to deny that some deposits were made of transported materials; that would be to deny the evidence of one's senses; but such deposits are of limited extent and have definite features, which distinguish them sharply from deposits made in the normal way.

#### CANNEL AND BOGHEAD.

The peculiar structure of cannel compelled geologists to recognize that in origin it differed from the ordinary coals. Newberry in 1857 asserted that it is merely vegetable mud, composed of macerated cells, deposited in ponds within swamps; Dawson in 1866, J. Geikie in 1872, E. B. Andrews in 1873 and Davis in 1880 enforced this explanation by their observations. In 1880, J. P. Lesley,<sup>138</sup> correcting an erroneous reference to his opinions, enlarged the conception and anticipated much of what has been announced in later years. His words are

<sup>138</sup> J. P. Lesley, Sec. Geol. Surv. Penn., Preface to Rep. H5, 1880, p. xxii.

"Cannel coal I regard as vegetable matter macerated in water, mixed with gelatinous water-plants and with the fine sedimentary clay which even the purest current-water always holds in suspension; and I ascribe the origin of petroleum in cannel, as I do the origin of the well-oil, to such water plants and to gelatinous water-animals."

Hutton and Fischer and Rust observed that resinous bodies, cell-like in character, are abundant in cannel and similar materials; von Gümbel in 1883 found in cannel a wonderful mass of disks and spores with flocky clay, macerated cells and algæ-like plants. Cannel and boghead are surprisingly like the Lebertorf of Purpesseln in East Prussia, which is a collection of parts of plants in a felt-like mass containing insects, leaves, separated cells and pollen grains, there being 1,000 of the last to each cubic centimeter. He felt compelled to believe that cannel, boghead and the Lebertorfs of Purpesseln and of the kurischen Haffs originated in similar manner; and he regarded them as closely related to the Plattekohle of Bohemia as well as to the Tula gas coal of Russia. He observed the algæ-like bodies in the Tasmanite of Van Diemens land. Früh's studies on peat appeared in 1883. He described the Lebertorf as a liver-brown gelatinous mass, consisting very largely of algæ, there being more than 60 species at one locality; he discovered that the algæ are of comparatively rare occurrence in true peat. Penhallow in 1892 found great numbers of amber-colored rod-shaped bodies in the felted mass of a Mesozoic cannel.

The results of studies by Bertrand and Renault<sup>139</sup> have been given in considerable detail on earlier pages. They examined the boghead of Autun in France and the Kerosene shale of New South Wales. Both contain the flocculent material observed by von Gümbel and Penhallow, in which are the algæ-like forms with pollen grains and vegetable débris. This, they regard as an ulmic jelly precipitated from the brown waters on which the fleurs d'eau floated. An infiltrated substance was observed at both localities, penetrating thalli of the algæ and, in the Kerosene shale, showing a fluidal structure. Some plants and parts of plants absorb it energetically and it penetrates the brown flocculent material or fundamental jelly. Bertrand's later studies were summed up in 1900, when he stated that these "charbons gelosiques" are accumulations of fresh-water algæ in a humic jelly, their fossilization being in the presence of "bitumen." Spores and pollen became fossilized but did not liquefy.

<sup>139</sup> "Formation of Coal Beds," I., these PROCEEDINGS, Vol. L., 1911, pp. 88-93.

They condensed bitumen energetically as did also the hard tissues of plants, which give glance coal. The fleurs d'eau descended in sheets with other accidental bodies, the speed of descent depending on the stage of water; if the water were low, the fundamental jelly would retard or prevent descent. Absolutely tranquil water was essential and the precipitation of ulmic matters by calcareous waters was constant. The "bitumen," absorbed by the various bodies, is regarded by Bertrand as a substance intervening wholly formed and coming from external sources. He suggests that it may have been in the water, but, in any event, he could find no evidence to show that it came from the decomposing plants.

The resemblance of these bodies to algæ was recognized by von Gümbel who saw more than one type, as did also Fischer and Rust, but they entertained enough doubt to prevent them from giving generic and specific titles to the forms. Some later students have felt compelled to dissent from Bertrand and Renault's conclusions respecting the algæ-like forms. Jeffrey<sup>140</sup> subjected the whole series of cannels and bogheads to microscopic analysis. By special treatment he succeeded in reducing the minerals to such condition that he could cut serial sections with the microtome; and in this way he made a great number of slides, giving opportunity for study not possessed by his predecessors. Jeffrey's results confirmed Renault's conclusion that the cannels are composed in great part of flattened spores from vascular cryptogams, which are shown better in American than in European cannels. According to Jeffrey, the bogheads of Kentucky, of Scotland and of Autun contain readily recognizable spores—the forms termed algæ by Bertrand and Renault being really spores of vascular cryptogams—and a similar conclusion is reached respecting the forms observed in the Kerosene shale. Jeffrey is convinced that the well-preserved individual elements in these minerals are spores and he thinks that cannel and boghead are alike in origin. The plates accompanying his memoir are elaborate.

Thiessen's<sup>141</sup> results have not been published and only a brief

<sup>140</sup> E. C. Jeffrey, "On the Nature of Some Supposed Algal Coals," *Proc. Amer. Acad. Sci.*, Vol. XLVI., 1910, pp. 273-290.

<sup>141</sup> R. Thiessen, "Plant Remains Composing Coal," *Science*, N. S., Vol. XXXIII., 1911, pp. 551, 552..

abstract of his preliminary announcement has appeared. The cannels studied by him are composed almost wholly of spore-exines with resins and cuticles in limited quantity. The so-called binding material in the intestices is distinctly of two substances, one, more or less homogeneous and colloidal; the other, more or less granular, the fragmentary residue of spore-exines. He rejects the algal theory of Bertrand and Renault as well as the sapropelic theory of Potonié, both being undemonstrable. The so-called algæ are not algæ, all forms but one having been proved to be exines of spores, either of Pteridophytes or Cycadofilicates or of both. A gelosic substance such as is called for by the theory is wholly absent.

The exact nature of these bodies, though of extreme interest from the botanist's standpoint, is of subordinate interest here. The important fact seems to be that while these bodies are comparatively rare in ordinary coals, they are predominating constituents of cannel and boghead, thus indicating a different mode of formation. One must bear in mind also, that animal remains are present abundantly in many cannels.

The brown fundamental matter of the cannels and bogheads is apparently the same as that which forms the basis of ordinary coal, and it is supposed by Bertrand and Renault to be a precipitate from the brown waters of swamp-pools, the precipitant being lime. Such brown waters are widely distributed especially in tropical regions. Samples of such water, obtained by Marcano in South America, were studied by Muntz<sup>142</sup> who discovered only a trace of lime in the dark water, which contains 0.028 gramme of organic matter per liter, yet has an acid reaction. The colorless waters are distinctly hard. The authors conclude that the acids were preserved in spite of aeration, because nitrification and consequent oxidation could not take place. When mingled with hard waters, the acids combine with the lime, nitrification begins and destruction of carbonaceous matter proceeds rapidly under influence of high temperature. The quantity of organic acids is small, even when the color of the water

<sup>142</sup> A. Muntz and V. Marcano, "Sur les eaux noires des régions équatoriales," *C. R.*, Vol. 107, 1888, pp. 908, 909.

is intense. Klement<sup>143</sup> found so little in the almost ink-black waters of Willebroeck that the material could not be investigated thoroughly. He observes that the brown waters of Gouda become de-colored very quickly in presence of pulverized calcite.

Humic and ulmic acids are certainly precipitated by lime; but one may not be regarded as hypercritical if he suggest that this can have very little to do with the supposed precipitation of ulmic matters in the ponds or stagnant waters of swamps. The deposit was laid down in water with undisturbed surface; that would be a stagnant pool, which could be filled only by rainfall or by seepage through the peat. But the seepage water, however rich it might be in lime at its entrance, would lose all while percolating through the peat, as organic acids would take it up; if, in course of time, an excess should exist and should reach the pool, the lime would find no organic acids there, as the bog itself would contain only the insoluble calcium compounds which could not be leached out in appreciable quantity. The condition would be the same, if the pond were fed by a stream meandering sluggishly through the swamp—no other would be possible under the supposed conditions. If the precipitation were a constant process and due to presence of lime, the precipitate should present abundant evidence, for there is no reason to suppose that the lime would be removed at any later time; the precipitation was not merely constant, but also so rapid that a thick deposit of boghead might accumulate in a single season. Everything, under such conditions, would be sealed up quickly. But analyses give no support to this conception of the origin, for lime is an unimportant constituent of bogheads. Liversidge<sup>144</sup> analyzed Kerosene shale from Greta and from Joadja creek in New South Wales. That from Greta contains about 28 per cent. of fixed carbon and nearly 16 per cent. of ash; but of the latter only 1.438 per cent. is lime. The mineral from Joadja creek has almost 16 per cent. of fixed carbon and 9 per cent. of ash; but of the latter only 0.3 per

<sup>143</sup> C. Klement, "Les puits artésiens de Willebroeck," *Bull. Soc. Belge de Géol.*, Vol. III., 1889, Mem. pp. 259-262.

<sup>144</sup> A. Liversidge, "Descriptions of the Minerals of New South Wales," Dept. of Mines, Sydney, 1882, pp. 162-164.

cent. is lime: no relation exists between the quantity of lime and that of fixed carbon or volatile. If one take the Joadja shale as containing only 10 per cent. of fundamental brown material, the condition remains, as the lime is but 0.027 per cent. of the whole, clearly insufficient for precipitation of the organic acids.

The supply of organic acids must have been very great in order that constant precipitation might be maintained, especially such abundant precipitation as to give several inches of fundamental jelly in the course of a single season—the water being stagnant. Everywhere, the brown waters, even when almost black, contain very little organic matter in solution, one part in 20,000 sufficing to give marked coloration and an acid reaction. The coffee-brown or greenish black waters of South America, according to Humboldt, are preferred to all others for drinking, being limpid and of agreeable flavor. Coville<sup>145</sup> has stated that water from the “juniper area” of the Dismal Swamp, with the color of tea, was the favorite source of supply for vessels departing on long voyages. This is a typical locality in the heart of the swamp; the water is acid in reaction and the flora is of the acid-resisting type, consisting of *Chamæcyparis*, alders and heathers. There seems to be no reason for supposing that, during Carboniferous times, the stagnant waters of swamps approached saturation with organic acids.

The suggestion that the “bitumen” is of extraneous origin, that it intervened fully formed, that it may have been in the water, is sufficiently perplexing. Bertrand finds no evidence that it was derived from the decomposing mass. It fills shrinkage cracks in the fundamental matter and it seems to have penetrated some tissues more readily than others—a condition which, for Bertrand, explains some differences in coals; glance, composed of barks and cuticles, absorbed much, but tissues in matt absorbed little. The algæ-like bodies had notable capacity for absorbing this bitumen. Renault<sup>146</sup> has expressed an objection, which, no doubt, presented itself to

<sup>145</sup> F. V. Coville, “The Recent Excursion into the Dismal Swamp,” *Science*, N. S., Vol. XXXVIII., 1911, pp. 871, 872.

<sup>146</sup> B. Renault, “Études sur le terrain houiller de Commeny; Flore fossile,” *Livr. 2*, 1890, pp. 687, 688, 701, 702.

many readers of Bertrand's memoirs. The invading bitumen must have possessed extreme fluidity, as it was injected into all parts of the vegetable débris, passing even through the walls of cellules; but that fluidity would have led to complete penetration of the sandstones and shales in which one finds the often widely isolated coaled plants; but no evidence of that penetration is seen. He objects also that if the penetration had been made into tissues, the coal should have the appearance of a compact resinous mass; but the coaled wood is porous and he found no "bitumen" in cells and vessels.

The term "bitumen," as employed by Bertrand, is extremely vague and its actual signification cannot be gathered from any of his writings. A reference to the La Brea (Trinidad) conditions suggests that a petroleum is the supposed source. This area was studied by Cunningham-Craig,<sup>147</sup> who states that the Rio Blanco sandstone has so much petroleum that, though tide-washed, it has 15 to 18 per cent. of sticky oil or soft pitch on the surface, and it constantly exudes similar material into the Pitch Lake. The existence of such asphaltic matter would be recognizable in the rock after any period, no matter how long—one finds asphalts in Carboniferous limestones and sandstones. The glance coal in sandstones is caking, rich in bitumen. The objection, however, is not insuperable. A light-colored oil with paraffin base might leave no notable trace in the sandstone. At the same time, one must bear in mind that paraffins do not change, and that the great supply is from Palæozoic rocks. If they penetrated the rocks and the tissues, it is certainly strange that certain solvents extract so little from coal or cannel or boghead. Destructive distillation, under similar conditions, obtains rather abundantly from coals some substances which are almost absent from petroleum.

But one cannot resist the query, Why go outside of the decomposing mass for the source of "bitumen"? If a source can be found in that mass, there seems to be no good reason for searching after recondite sources. Coals, even those of Carboniferous age,

<sup>147</sup> E. H. Cunningham-Craig, "Preliminary Report on Guapo and La Brea District," Council Paper, No. 30, 1906, pp. 3, 4.

very often contain macroscopical masses of resins, which, in color, are very similar to the material revealed by the microscope. Palæobotanists have discovered in ferns certain organs closely resembling those which, in modern ferns, secrete resins and there appears to be good reason for supposing that Sigillarids yielded much resinous material. The gums, resins and other substances, originally soluble or rendered soluble by microorganisms, would be deposited in tissues and crevices. The feature is familiar in recent bogs and those of the Quaternary, where the fluidal ulmic and other allied substances fill not only cavities in the bogs but also in the underlying bed.

The formation of the cannels and bogheads would seem to be explained sufficiently by the earlier conception, which has the double merit of simplicity and of accordance with conditions known to exist. The minerals consist of vegetable muds with contribution more or less important by plants and water animals. The great abundance of spores and pollen grains is paralleled in modern times by showers of pollen, the "sulphur showers" in wide areas; fresh-water algæ abound in pools of actual swamps—possibly their existence in Coal Measures times is still problematical. Modern sapropelic deposits bear, in many ways, very striking resemblance to cannels and bogheads, though certainly there is no evidence of a "bitumen" infiltration. But the hypothesis of extraneous origin of the "bitumen" seems to be unnecessary, so that, to be accepted, it should be supported by incontestable evidence. Lesquereux<sup>148</sup> cites Ziegmann's analysis of an impure peat, which yielded 6.2 per cent. of wax, 0.4 per cent. of resin, and 9 per cent. of "bitumen." It is sufficiently well known that peat, subjected to destructive distillation, gives ample evidence of containing bituminous matter. Theinius, cited by Davis,<sup>149</sup> has shown that air-dried peat yields 6.39 per cent. of petroleum, lubricating oil and paraffin wax, besides 40 per cent. of tar oil. The dried tar yields 54 per cent. of the same substances and a notable quantity of ammonium sulphate. The

<sup>148</sup> L. Lesquereux, Sec. Geol. Surv. Penn., Rep. for 1885, p. 117.

<sup>149</sup> C. A. Davis, "The Uses of Peat," U. S. Bur. of Mines, Bull. 16, 1911, p. 136.

Ziegler process for securing these substances from peat has been tested on the commercial scale, with results approximating those obtained by Thenius.

Autochthonists claim that their doctrine is in accord with what is known of nature's processes and that its fundamental assumptions can be verified by observation. They recognize that in some respects, modern differ from ancient conditions. The distribution of heat on the earth's surface is clearly unlike that during the Carboniferous; the dominant plants of modern forests did not exist at that time. But the Carboniferous plants have relatives in the modern flora; the chemical laws governing decay of plants have remained the same throughout, as proved by a continuous record; the erosive action of running water has shown no change in method; the laws controlling the deposit of transported materials have remained unaltered from the earliest times. There have been great changes in animal and vegetable life; many forms have become fitted to new habitats; but such modifications are not unknown in modern times and they are not regarded as strange.

The modern peat bog is taken to be the analogue of the ancient coal bed. The vegetation is dissimilar, but that is unimportant. Land-plant material, be it of one sort or another, gives peat under the proper conditions. The final substance is practically the same in the cedar swamps of New Jersey, the cypress swamps of the southern states, the swamps of Scandinavia and in the buried swamps of the southern states, the swamps of Scandinavia and in the buried swamps of the Ganges, western India or the Mississippi; and, in all of those, it is the same as that in the great tropical swamps of Florida, Demarara and Sumatra, where it is derived from wholly different types of plants. Everywhere, the final result of decomposition is the same; the plant material is converted into a mass of organic acids and salts, enclosing large or small woody fragments of resistant composition. The difference in plants does not affect the matter under consideration; Carboniferous plants were converted into peat when exposed to the proper condition, just

as are modern plants, the same organic materials being common to them both.

The vast extent of some coal fields is urged as a vital objection to autochthony, because there are no delta-plains so great as the larger coal fields of America or China. But this is not correct. The Ganges-Indus flood plain area, like that of the Yang-tse-kiang, is as great as the Appalachian basin and each has, in a considerable part of its extent, conditions favoring accumulation of peat. Too many writers commit the error of confounding extent of coal field with extent of coal bed, and they refuse to believe that peat could accumulate synchronously throughout the vast areas. Though in no wise enamoured with modern causes, they appeal to them quickly and cite the limited extent of modern peat bogs, none of which resembles the Appalachian coal basin. But these writers forget or do not know that coal was never accumulating at any one time throughout a great field. Even at the time of the Pittsburgh coal bed, with its probable area of more than 12,000 square miles, there was not synchronous accumulation. During the earlier part of that bed's history, as shown on an earlier page, coal was forming in less than one third of the area; and during the later portion there was no accumulation in perhaps half the area. So with other beds; coal accumulated at separated localities, a few square miles or hundreds of square miles in extent, sometimes near together but at others far apart. During most of the time, conditions were unfavorable to coal accumulation in probably by far the greater part of the more extensive basins. One has to consider not vast sheets of coal, but local deposits. The condition, most probably, was that now seen in Holland, Belgium, northern France and northern Germany, where the peat deposits are in separated areas, large and small; but they are contemporaneous and mark a definite horizon. The important continuous area of Holland, Belgium and northern France, now largely buried, is nearly as large as that on which any bench of the Pittsburgh seems to have accumulated; and the thickness in some places is important. The Everglades of Florida is almost as extensive and is only one of the many swamps in Florida, where the distribution is very like that at some coal horizons in the

Appalachian basin. The thickness of certain coal beds has been regarded as weighing heavily against autochthony. But the modern peat bogs, which have been studied in detail, are youthful, of only post-glacial origin. Possibly in course of time there may be at many places peat deposits of immense thickness like those in some portions of the Alaska tundra; but it is more probable that no deposit will excel the average coal bed; reclamation of marsh land has checked peat accumulation in much of Germany and is likely to do it throughout the civilized world.

The earlier writers studied mostly the treeless moors; but many features of coal beds, wanting in those, are reproduced in the Waldmoors or forested swamps, which are familiar in much of northern Europe and in the United States. In all probability they are of much greater extent on the broad plains of the Amazon and Orinoco, where, however, they have been studied only as forested swamps and not as producers of peat. Kuntze has shown that similar areas of vast extent in the Paraguayan region are genuine Waldmoors. The prevailing flora of such swamps in the temperates consists of conifers, heathers, sedges, with ferns and, usually as late arrivals certain mosses. These plants are in a habitat resembling that in which the Coal Measures plants are supposed to have lived, so that there should be important features in common, if the doctrine of autochthonous origin be true—for that asserts that the older flora grew in areas covered with decomposing vegetable materials.

The swamp flora of modern times consists very largely of plants with marked xerophytic or drought-resisting features; similar characteristics have been recognized in the Coal Measures flora, as well as in those of some later coal-making times. The facts that some plants living in swamps are found elsewhere, flourishing on arid or semi-arid soils, has led to the suggestion that they may be only interlopers. Henslow<sup>150</sup> has conceived that the xerophytic features of *Stigmaria* and *Lepidodendron* could have been acquired by living

<sup>150</sup> G. Henslow, "On the Xerophytic Characters of Certain Coal Plants, and a Suggested Origin of Coal Beds," *Quart. Journ. Geol. Soc.*, Vol. LXIII., 1907, p. 283.

long on dry ground, and that they could have been retained even after the forms had migrated to a swamp. Seward and Hill,<sup>151</sup> on the other hand, recognized indications in the structure that the conditions of growth required development of characteristics associated with the xerophytic habit.

The readiness with which certain types of plants accommodate themselves to the extreme dampness of swamps or to the aridity of sands has been, long time, subject of investigation. Davis<sup>152</sup> says that swamp plants growing at the water-level are drought-resisting; their leaves are contracted, have dense cuticle and are often coated with waxy or resinous materials. The condition against which they are protected exists in swamps as well as in dry soils. Peat, though holding much water, parts with it reluctantly; even after the centrifugal test, the retained water equals 142 per cent. of the weight of the dried peat, and the material appears to be merely damp. Under similar conditions the retained water in sand is but 2 to 4 per cent. There is physiological dryness in peat; the water is ample but not available.

Coville<sup>153</sup> has shown that another agency is important. He recognizes fully the fact of physiological dryness, but he regards another agency as of equal or in some cases of much greater importance. The blueberry grows luxuriantly in swamps, but equally well in the sandy soil of pine and oak woods on the Coastal plain and in the spruce woods of the White mountain slopes. The factor determining distribution of this plant is acidity, it cannot thrive if the soil be alkaline or neutral. The surface in the pine and oak woods, as in the spruce forests, is covered with a litter of decomposing twigs and leaves, whence organic acids are carried to supply the plant's needs. The rootlets are without the fibrous appendages, which

<sup>151</sup> A. C. Seward and A. W. Hill, "On the Structure and Affinities of a Lepidodendroid Stem," *Trans. Roy. Phys. Soc. Edin.*, Vol. XXXIX., 1900, p. 928.

<sup>152</sup> C. A. Davis, cited in "Formation of Coal Beds," these PROCEEDINGS, Vol. L., 1911, p. 601.

<sup>153</sup> F. V. Coville, "Experiments in Blueberry Culture," *Bur. Pl. Ind., Bull.* 193, 1900; "The Formation of Leafmold," *Journ. Wash. Acad. Sci.*, Vol. III., 1913, pp. 87-89.

characterize ordinary upland plants, so that the absorbing surface is reduced, while the protected leaves prevent rapid loss by evaporation. The rootlets contain abundantly a mycorrhizal fungus, which fills many cells and forms a network outside on the cell wall. Similar fungi were discovered by Miss Ternetz in rootlets of the cranberry and other swamp plants. Coville finds them in most of the acid-loving plants, such as the laurel, birch, chestnut, conifers, oaks, club mosses, ferns, orchids, and thinks probable that they convert the unavailable nitrogen of acid, peaty soils into available nitrogen, so as to provide proper nutriment to the plants.

Fungi, myriapods and insect larvæ are efficient in hastening decomposition. Coville says that myriapods are almost incredibly abundant in the very acid laurel (*Kalmia*) peat. Renault<sup>154</sup> presented to the geological Congress at Paris a synopsis of his great work on the "Microorganismes des combustibles fossiles," in which he indicated the work performed by lower types of life. Study of the Grand' Croix flints proved that micrococci and bacilli abound in that petrified peat as they do in modern peats; he found them abundant in bogheads, cannels, lignite and coal. Mycelia of minute champignons are present in the macrospores of Kentucky cannels as well as in wood fragments of coal beds. The close resemblance to peat conditions led Renault to the conclusion that the plant materials were infected during sojourn in swamps before being swept away by floods, which he believes were extremely violent during Palæozoic time.

#### CONDITIONS DURING COAL MEASURES TIME WERE FAVORABLE TO ACCUMULATION OF PEAT.

Assuming that the writer's conclusions<sup>155</sup> presented on an earlier page are approximately correct, one must regard the Appalachian basin, at the close of the Pottsville, as in great part an irregular plain, raised not far above sea-level and liable to flooding by many

<sup>154</sup> B. Renault, "Du rôle de quelques bacteriacées fossiles au point de vue géologique," *C. R. VIIIe Cong. Géol. Int.*, 1901, pp. 646-663.

<sup>155</sup> "Formation of Coal Beds," III., these PROCEEDINGS, Vol. LI., 1912, pp. 552, 553.

rapid streams issuing from the Appalachians at the east and the Canadian highlands at the north. The sluggish drainage was rendered more uncertain by irregular subsidence, by formation of gentle plications as well as by local elevation or subsidence in more or less extensive areas. Almost the whole basin was land at the beginning of the Pennsylvanian, as appears from the unconformity between that and the underlying Mississippian, which is marked by an eroded surface in all parts of the area, and by the absence of the Pocahontas and New River beds from the northern portion, except in part of the anthracite area. The gradual northward advance of the Beaver deposits evidences the slow and frequently halted subsidence. The conditions were wholly similar in Indiana and Illinois, west from Cincinnati, and they are equally distinct in Iowa and Missouri, west from the Mississippi river. In all this vast area of perhaps half a million square miles, one finds the unconformity between Mississippian and Pennsylvanian marked by extended erosion, and the first beds of coal, in any district, are irregular, occupying more or less isolated basins in the eroded surface.

The relations of erect tree stems are important in this connection. Much energy has been expended in the effort to prove that transported trees can be deposited in vertical position; but all that energy has been wasted, for no one, familiar with the matter, ever had any doubts respecting the matter. The possibility could not be disputed; the doctrine of chances converted it into a probability and the existence of snags in the Mississippi river made it a certainty.

All such discussion is foreign to the subject and tends to divert attention from the only point at issue, which is, Are these particular stems *in situ* or not? Each occurrence stands alone and it must be considered apart from all the rest.

Erect stems have been observed in all coal fields and often in such relations that not merely unscientific observers but also trained geologists feel compelled to recognize that they are *in loco natali*; Jukes, when he saw the Parkfield stumps, admitted, though somewhat grudgingly, that the trees certainly looked as though they had grown there and that perhaps they had. The observations by Beckett, Ick, Darwin, Goeppert, Sorby, Barrois and others, recorded in earlier

pages, describe trees as clearly *in situ* as are those of Senftenberg, described by Potonié, or the stumps in cedar swamps of New Jersey or the cypress swamps of Louisiana. One is amazed at the manner in which the evidence is received, for not infrequently there is an implication that all may be mere assumption, that possibly other explanations may be found, since no one saw the trees growing. It is an assumption, as is almost everything in the reasoning of everyday life. The writer has seen many extensive areas of cleared land on which the stumps remained; he had not seen the forest in existence, but the relations of the stumps convinced him that they were *in loco natali*. Buried or submerged forests are commonplace now.

The argument in favor of *in situ* origin is based on clear-cut observation. The branches of *Stigmaria* are interlaced in such complex fashion that the most ingenious efforts have failed to explain away the phenomenon, and allochthonists have found themselves compelled to resort to the remarkable suggestions of débâcles and transport *en bloc*; but those were impossible amid topographical conditions such as, according to both allochthonists and autochthonists, must have existed in the Coal Measures areas. It is absolutely certain that no such disturbances accompanied the deposition of the rocks holding the tree stumps, for every feature indicates gentle action; the rhizomas are spread out in normal condition and retain their slightly attached appendages, while the rock itself is the same in all features as it is elsewhere. In many localities, such as those described by Schmitz, Ick, Lesquereux and others in the Coal Measures, Potonié, Darwin and others in the Tertiary, the spaces between the trees are such as are found in forest growth. In some cases, such as those mentioned by Goeppert, Dawson, Grand'Eury and others, successive growths on the same site are recorded, roots of the newer generation descending amid the stems of their predecessors. Not rarely, the roots pierce impressions of leaves previously buried in the soil. At times, prostrate stems are abundant in the intervals between erect stems and frequently the former outnumber the latter; just as one sees on the surface of forested swamps along the Atlantic coast and in the southern states. In not a few cases, the debris of leaves and twigs accumulated about the bases

of the trees, becoming a thin coal bed overlying the roots and extending to a considerable distance. This too is a familiar condition in modern times. "Upland peat," as Coville has termed it, sometimes accumulates to notable thickness in conifer and oak forests: he reports a thickness of 5 feet in some areas. The writer knows only too well that such peat accumulates to a thickness of more than 3 feet in the forests of gigantic firs within New Mexico; on more than one occasion, his camp narrowly escaped destruction because the peaty material had not been removed to the bottom before a fire was lighted.

Erect stems in many cases are cut off abruptly at top or bottom, as abruptly as though they had been sawed off. For this condition, which occurs so often in the roof of coal mines, there is no explanation aside from growth *in situ*. The absence of roots to sawed off stems in the roof, and of crowns to sawed off stems in the mur can be due only to slipping of the coal, which destroyed the original continuity.

The great number of erect stems discovered in the narrow exposures of mines and on the still more limited space of natural outcrops renders wholly reasonable the suggestion that, if coal were mined by stripping, fossil forests would be found abundantly in all fields, as Binney long ago suggested for the Lancashire region. The stems, which have been found, are associated in many cases with ripple-marked sandstones, the ripples at times resembling the complicated forms characterizing dunes or loose sand. Altogether, the evidence showing that the trees, under consideration, grew where they are found, is in every respect as conclusive as is the evidence that the logs between Cape Malagash and Wallace Harbor, described by Dawson,<sup>156</sup> are a petrified raft of driftwood, or that the irregularly distributed battered timber found in sandstones is not a growth in place. The reasoning is the same in both cases, an application of knowledge gained by actual observation to explain conditions where actual observation of the process is impossible.

While the existence of great numbers of trees *in situ*, so dis-

<sup>156</sup> J. W. Dawson, "Some Fossils found in the Coal Formation of Nova Scotia," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, pp. 132-136.

tributed as to suggest strongly that they belonged to forests, may have no direct bearing on the formation of coal beds, it has an extremely important indirect bearing. It is part of the proof that the region was a land area, covered more or less with vegetation. The other elements of the proof have been set forth with ample detail in Part III. They are, the extraordinary horizontality of the strata in many thousands of square miles, where the disturbing forces have not acted, showing marked resemblance to conditions on the Siberian steppe, described by Belt, or to those on the Gangetic plains, described by Blanford; the absence of plant remains in sandstones and shales in great areas; the presence of coal and shale pebbles in many deposits; the gradation in size of pebbles, indicating rehandling by streams; the extreme freedom from fine material along definite lines of coarse rocks, distinct evidence of river selection; the buried valleys, scores to hundreds of miles long; the gullied coal beds; the widely extended sub-aerial erosions: the vast deposits of fine shales, proof of long sub-aerial exposure of the rocks, whence they were derived; the shallow water character of the localized marine limestones, which occupy definite areas, resembling estuaries extending into valleys; the ripple-marks, sun-cracks and footprints, observed at many horizons. Some of these features, if they existed alone, might be explained in other ways; but they do not occur alone. They must be considered as a whole. The conditions were such as to favor the accumulation of peat; the coal beds must have accumulated under practically sub-aerial conditions—unless one accept a flexibility of the earth's crust, many times greater than that which some allochthonists imagine is demanded by autochthonists.

#### THE PEAT DEPOSITS RESEMBLE COAL BEDS.

Grand'Eury says that in the coal the plants have been broken up and the parts scattered; fruits and leaves are separate from their stems; layers of bark have been displaced; the interior portions of stems have disappeared and only the flattened cortex remains; woody parts have been dispersed as fusain; stems are split and torn; *Cordaites* leaves are imperfect; everything, bark or leaf, is

fragmentary; a great part of the tissues was transformed into a vegetable pulp, which makes up most of certain coal beds. Long ago Lesquereux described mature peat in very similar terms, the fragmentary materials being embedded in an amorphous material, consisting of organic acids and their salts. Von Gümbel's description is much the same; the amorphous material, much of which was originally flocculent, is his Carbonhumin, which binds together the plant fragments and the often abundant mineral charcoal, which he terms, *Torffaserkohle*. The cementing material, soluble in the bog, becomes insoluble on drying. Grand'Eury's description of coal applies equally to matured peat, especially well to that of the American cypress swamps. It is thoroughly applicable to the "coal balls" as well as to the Grand'Croix flints, all of which are regarded by investigators as petrified peat.

In one respect, however, the description does not apply to many peat deposits. Coal often consists largely of flattened stems, the interior having disappeared. On preceding pages, the presence of prostrate stems and erect stumps has been mentioned as characteristic of old or new Waldmoors in all parts of the world. According to Harper, such stems and stumps are so abundant in many Florida swamps as to make the peat commercially worthless; Cook says that in the New Jersey swamps stems of white cedar are so numerous that one has difficulty in thrusting a sounding rod through the mass. Similar crowding of stems appears to be a familiar feature in the deposits of northern Europe, according to all observers from De Luc to the present. In very large part, the wood is fairly well preserved; the Irish bog oak and the New Jersey white cedar are utilized by cabinet-makers. Grand'Eury's description affords the explanation. There was little woody material in most of the Carboniferous trees; there is much in the conifers and oaks of modern swamps. But woods of other types do occur in flattened condition within peat; von Gümbel found them at the depth of only one meter, so that the collapse was not due to pressure. Früh made the same observation in the great Digenmoor of the Bavarian highland; the late-Quaternary *Schieferekohle* contains flattened stems of harder woods—and here too the deformation is not due to pressure, for cones, not de-

formed, lie alongside of the flattened stems. Erect stumps are of comparatively rare occurrence in the coal, but they abound in Tertiary and Quaternary deposits. Evidently, cellulose predominated in the older forms as lignin or woody tissue predominates in the newer. As Andersson<sup>187</sup> says, if the cell walls of all plants had consisted of pure cellulose, we probably should have found scarcely a trace of the plant world which once existed upon the earth.

Peat is laminated but not in all cases like coal, for in the latter, the lamination is due very often to flattened stems. The existence of well-preserved woody stems in many swamps obscures the lamination. But Lesquereux long ago recognized the layer-like structure of new peat, where the thickness of layers is not far from an inch, while in the mature peat it is not more than an eighth. Von Gümbel ascertained that compression makes the lamination of even sphagnum peat distinct.

Peat beds have definite benches like coal beds. Lesquereux says that in some bogs the ash is different in color. Such benches are as well marked in peat deposits of northern Europe as in any coal bed and they are equally well marked in the Schieferkohle of Switzerland, so that the history of each bench is clear. The passage from one to another is abrupt, as appears from sections given in Part II. There are, very often, distinct partings, consisting of a crust formed during periods of dryness, when growth of peat is checked and oxidation succeeds; this crust persists after growth has been resumed. Its character is very similar to that of the thin partings in the Pittsburgh coal bed, which consist of mineral charcoal with mostly impalpable inorganic matter, such as would remain after oxidation of vegetable substance. Explanation of those partings in this way seems to very simple and not far-fetched; lowering of the water-level only a few inches would suffice. The period during which that bed accumulated was one of irregular and more or less differential subsidence.

On a preceding page, it was shown that the ash in coal is from less than 1 per cent. to any per cent., the passage from coal to carbona-

<sup>187</sup> G. Andersson, "Studier öfver Finlands Torfmossar och fossila Kvar-tärflora," *Bull. Com. Géol. de Finlande*, No. 8, 1898, p. 191.

ceous shale being continuous, from the chemist's point of view. So with peat, for one may find clean peat with little ash passing gradually into ordinary mud within a mile or less. Coal at times has very much less ash than was contained in the plants whence it was derived; the same is true of peat, which, as a commercial product, has from 1 to 20 per cent. But sphagnum has from 3 to 4 per cent., yet Vohl analyzed a sphagnum peat which contained only 1.25 per cent. of ash.

Coal beds are buried deeply under detrital deposits; but those deposits were laid down, one at a time. Peat beds are of late-Quaternary or Recent age; opportunity for deep burial has come to few of them. But buried bogs are a familiar phenomenon and in some cases the cover is thick. At one locality in Ohio, a bed, 15 to 20 feet thick, underlies 90 feet of sands and gravels; in Indiana, one bed, 2 to 20 feet thick, has been found underlying a considerable area at a depth of 60 to 120 feet. The buried peats of Scotland, France, Germany, Holland, Switzerland, equally with the buried cypress swamps of the Mississippi region and the great buried swamp of the Ganges area, all afford proof that it is not the necessary fate of peat bogs, *in situ*, to be destroyed by oxidation.

The extent of modern peat deposits compares very favorably with that of coal beds; that, extending across Belgium from Holland into France, equals the extent of the Pittsburgh coal bed as it exists to-day. The upper peat bed of the Gangetic plain seems to have been proved in an area of nearly 2,800 miles, exceeding that of any American coal bed except the Pittsburgh and two in the Middle Pottsville. The Alaskan tundra has much greater continuous areas and at some localities the thickness is very great.

Coal beds frequently divide and in some cases the divisions reunite. Peat deposits do the same, as Lorie's records show. True, the divergence of peat benches is not so remarkable as that observed in some coal beds but otherwise the condition is the same; at times, the origin of other features is suggested. The irregular subsidence of the New Madrid region on the Mississippi affected an area of rather more than 2,000 square miles; when that depressed region has been filled up by silts and overspread by a new swamp, division and re-union will be as distinct as it is in the Mammoth coal bed.

Peat deposits rest as do coal beds on sandstone, shale, clay or limestone and the limestone may be either fresh water or marine. Like coal beds they underlie a roof of any sort and at times they are intercalations in marine calcareous shales. The association with marine beds is clearly no evidence of deep water or of flexibility in the earth's crust.

#### IN CONCLUSION.

The coal beds and the associated rocks are of land origin; the detrital deposits are those made by flooding waters on wide-spreading plains; the coal beds, in all essential features, bear remarkable resemblance to peat deposits, sometimes to the treeless moor, more frequently to the Waldmoor.

But many matters still await explanation, among them some which the writer hoped to explain as result of this study. And they are likely to wait long. No extensive coal field has been studied closely; in spite of the imposing array of skeleton sections, there is an astounding lack of detail respecting many matters which appear to have no important bearing on commerce. Until the topography and geography of the Coal Measures land have been worked out, geologists must be content merely with probabilities concerning the remarkable bifurcation of some coal beds, the variations in subordinate intervals between two approximately parallel coal beds, the presence of huge blocks of transported rock in coal and the associated rocks, the immensely long periods of stable conditions indicated by the thickness of some coals, and some others which will suggest themselves to the reader. It is true that these are all purely local in character, but they occur at many though somewhat widely separated localities. The explanation for some of them must await the solution of certain problems in physical and chemical geology, lying wholly outside of the questions considered in this memoir.

These matters, however, do not concern the general problem with which this study has been concerned. In the present state of knowledge, as revealed in the literature, that finds its solution in autochthony alone.